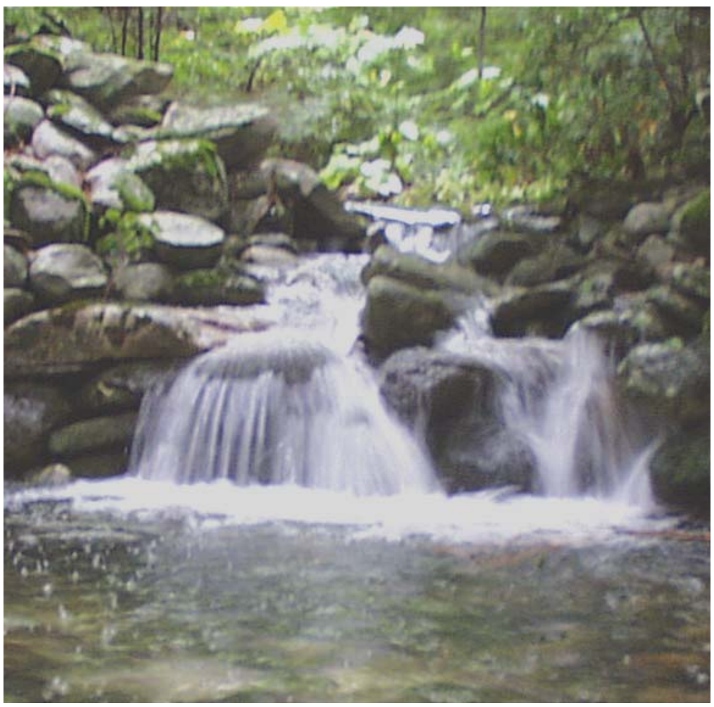
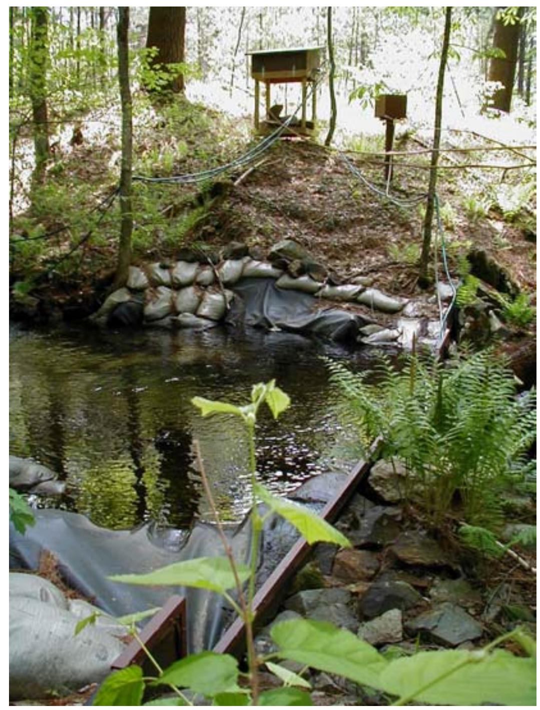
Department of Conservation and Recreation[1]
Division of Water Supply Protection

Water Quality Report: 2003
Quabbin Reservoir Watershed
Ware River Watershed





[1]Formerly the Metropolitan District Commission

June 2004

ABSTRACT

This report is a summary of water quality monitoring results from thirty-six water quality monitoring stations established throughout the Quabbin Reservoir and Ware River watersheds. The Department of Conservation and Recreation, Division of Water Supply Protection (formerly the Metropolitan District Commission, Division of Watershed Management) is the state agency charged with the responsibility of protecting Quabbin Reservoir and other natural resources in order to protect, preserve and enhance the environment of the commonwealth and to assure the availability of pure water to future generations. As part of this effort, the Environmental Quality Program at Quabbin maintains a comprehensive water quality monitoring program to ensure that Quabbin Reservoir and its tributaries meet state water quality standards. As part of this task, the Environmental Quality Program maintains a state certified laboratory, performs the necessary field work, and interprets water quality data and prepares reports of findings. This annual summary is intended to meet the needs of the decision makers, the concerned public and others whose decisions must reflect water quality considerations.

Quabbin Reservoir water quality in 2003 satisfied the requirements of the Filtration Avoidance Criteria established under the EPA Surface Water Treatment Rule. Monitoring of tributaries is a proactive measure aimed at identifying general trends and problem areas that may require additional investigation or corrective action. Compliance with state surface water quality standards among the tributaries varied with minor exceedances attributed to higher pollutant loads measured during storm events, wildlife impacts on water quality, and natural attributes of the landscape.

The appendix to this report includes summary information on mean daily flows of gaged tributaries, water quality data summary tables, plots of reservoir water quality results, and time series plots of individual water quality parameters.

Acknowledgments:

This report was prepared by the Quabbin Environmental Quality Section of the DCR, Division of Watershed Management. Scott A. Campbell, Environmental Engineer II was the principal author of this report. The author acknowledges Robert P. Bishop, Environmental Analyst IV for his support and guidance provided as the Supervisor of the Environmental Quality Section. Many thanks go out to Peter Deslauriers, DCR Bacteriologist, whose primary responsibility it was to ensure that the laboratory ran smoothly on a day-to-day basis. Paul Reyes, Environmental Engineer II was primarily responsible for data management but also provided significant assistance in editing and data analysis presented in this report. Dave Worden, DCR Limnologist wrote sections of this report pertaining to his work on monitoring reservoir nutrient and phytoplankton levels. Matthew Hopkinson, Environmental Engineer III and Lisa Gustavsen, Environmental Analyst III, provided significant assistance in editing and reviewing a draft version of this report.

Additional assistance was provided by Philip Lamothe, GIS Specialist who provided Geographical Information System data, maps and support. David Supczak, Joseph P. Burek, Peter Izyk and Doug Williams of the Quabbin Civil Engineering Section provided meteorological and reservoir yield data reproduced in this report.

The U.S. Geological Survey through a cooperative agreement established with the DCR provided tributary flow data appended to this report.

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ADDITIONAL INFORMATION – DCR Water Supply Protection at www.mass.gov/mdc/water.htm

1.0 CHARACTERIZATION OF THE QUABBIN RESERVOIR WATERSHED SYSTEM

Figure 1 shows the Quabbin Reservoir, Ware River and Wachusett Reservoir watershed system that supplies drinking water to Boston and 45 other member communities that make up the MWRA service territory. The largest of the three interconnected sources is Quabbin Reservoir, a 412 billion gallon impoundment of the Swift River located in Central Massachusetts. Quabbin Reservoir water transfers to Wachusett Reservoir via the Quabbin Aqueduct Intake at Shaft 12 typically account for more than half of MWRA's system supply. Quabbin Reservoir also supplies a much smaller amount of water directly to three western Massachusetts communities via the Chicopee Valley Aqueduct (CVA). Water is delivered to the service communities via two, gravity fed aqueduct systems also depicted in Figure 1. The Quabbin Aqueduct intake at Shaft 12 is located along Quabbin Reservoir's eastern shoreline in Hardwick, Massachusetts. The CVA intake lies at the base of Winsor Dam in Belchertown, Massachusetts. DCR has maintained a SWTR, filtration waiver status for its CVA supply since 1992. A filtration waiver for the Wachusett Reservoir also exists. The focus of this report is the Quabbin Reservoir watershed and supplemental supplies from Ware River diversions. Land use characteristics of the contributing watersheds are summarized below.

Quabbin Reservoir watershed is about 19 miles long, 13 miles wide, and contains roughly 120,000 acres. More than 90% of watershed lands are forested and the Department of Conservation and Recreation owns and controls 53,000 acres (55%) for water supply protection. The majority of non-DCR owned land is maintained as private forest. Developed lands in the watershed can be characterized as sparsely populated and having limited agricultural sites.

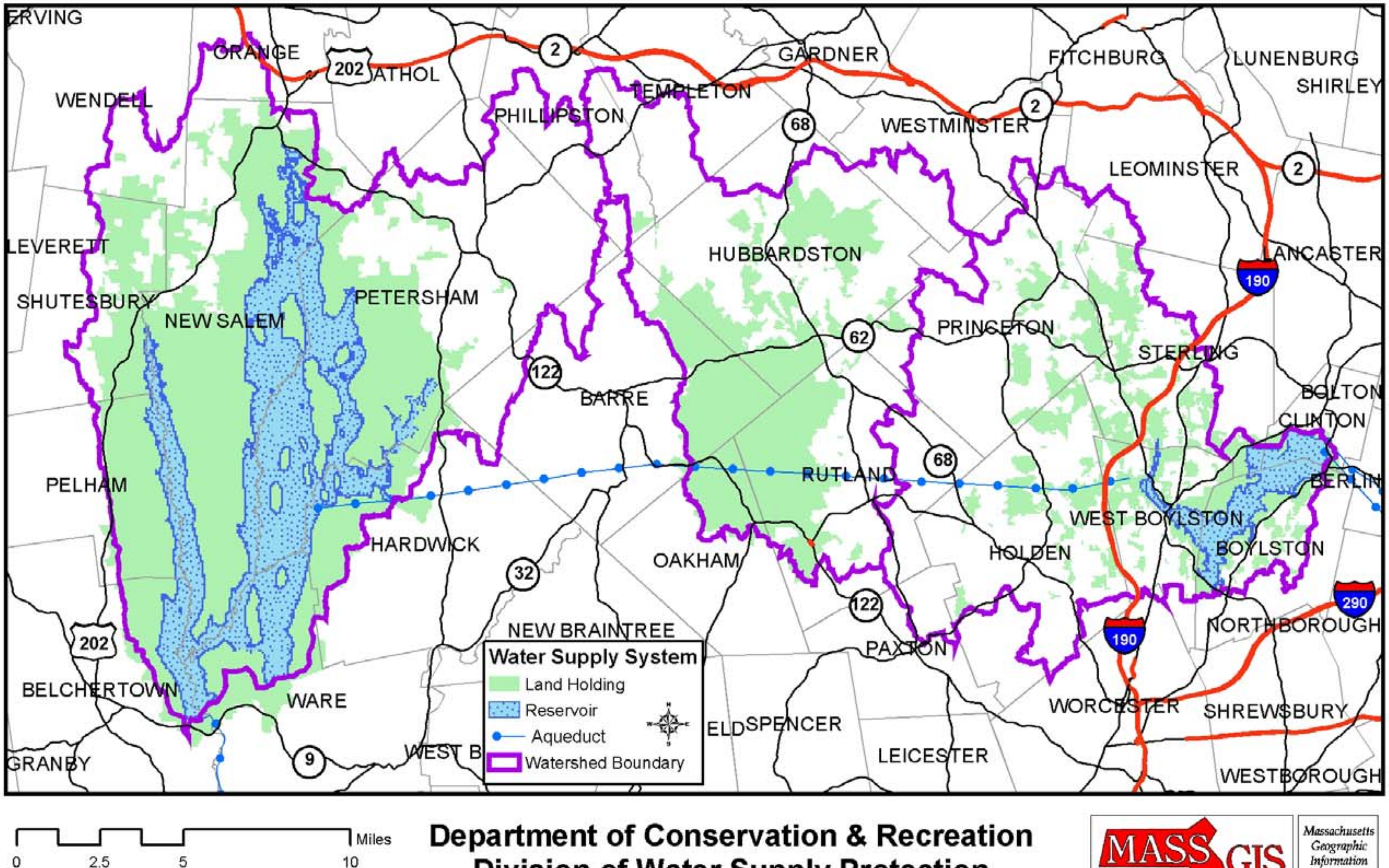
Aerial Photo: Winsor Dam, Quabbin Reservoir.

The Ware River watershed is about 11 miles long, 7 miles wide, and contains roughly 62,000 acres. Nearly 75% of the watershed is forested and the DCR owns and controls 22,000 acres (35%) for water supply protection. The vast majority of private lands are maintained as forests and developed lands consist primarily of low density residential and agricultural sites. Waters from Ware River are diverted into the Quabbin Aqueduct at Shaft 8 in Barre and directed west towards Quabbin Reservoir via gravity flow. Diversions are limited to periods when Ware River flows exceed 85 MGD and require DEP approval unless conducted during the allowable diversion period from October 15 to June 15. Water from the Ware River enters reservoir at Shaft 11A, located east of the baffle dams in Hardwick.

No wastewater treatment plant discharges are currently permitted in tributaries to either of the three water supply watersheds. Industrial and commercial land uses throughout the Quabbin Reservoir and Ware River watersheds are limited and make-up less than ½ percent of the total land area.

Active Water Supply Watersheds Base Map

Quabbin Reservoir, Ware River & Wachusett Reservoir Watersheds



Department of Conservation & Recreation
Division of Water Supply Protection
Map produced by GIS Staff; Revised August 14th, 2003.

MASS GIS Massachusetts Geographic Information System
Massachusetts Executive Office of Environmental Affairs - 2003

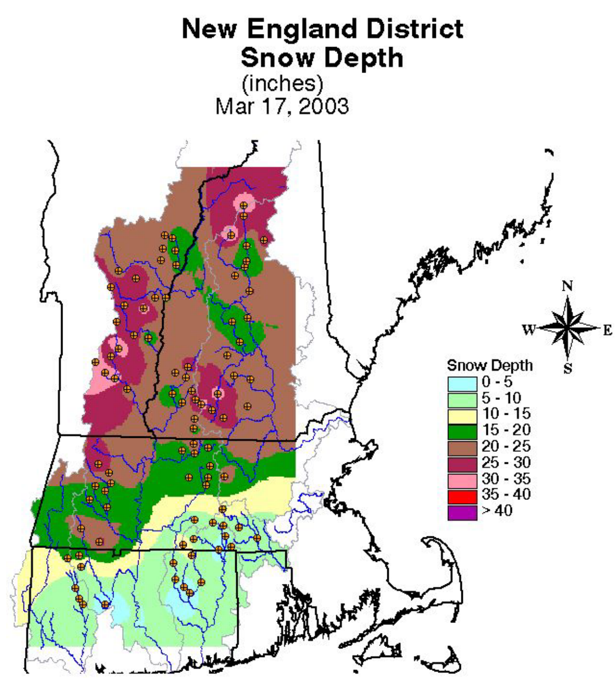
Figure 1

PRECIPITATION

Since 1939, DCR and its former predecessor the Metropolitan District Commission have maintained a weather monitoring station at the Administration Complex in Belchertown, Massachusetts. Presently, DCR staff collects daily (Monday thru Friday) temperature, rainfall, and snowfall data at this station located at the base of the reservoir. Historically, annual precipitation has averaged just slightly below forty-six inches. Precipitation in the form of snow and rain is distributed equally throughout the year with average monthly precipitation ranging between 2.95 and 4.37 inches (months of February and August respectively). **Figure 2** summarizes monthly precipitation data from 2003 and compares it to historical data from the 1939-2002 reference period.

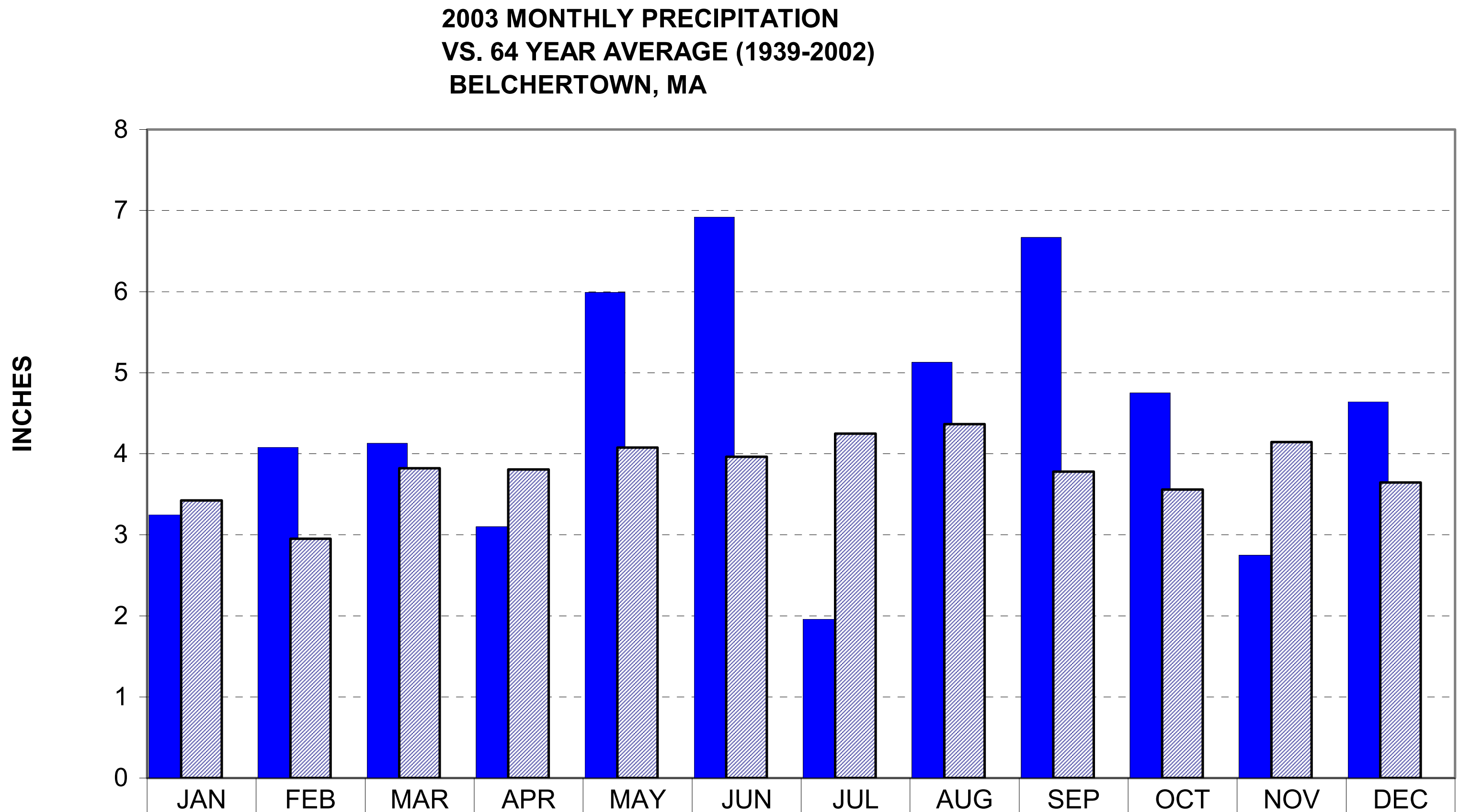
Total precipitation for 2003 at 53.37 inches exceeded the 64 year average by 7.6 inches. The 2003 precipitation total represents a 21.6% increase from 2002 totals and ranked among the top 20 percent of records kept since 1939. Six months had wetter than normal precipitation totals with surpluses of one inch or more, and these included February, May, June, September, October and December. Four of the wet months were especially wet with totals ranking among the top 20 percent of records kept since 1939. Monthly precipitation totals were within a normal range of conditions for the months of January, March, April, and August. Only two months, July and November, were drier than normal with deficits of one inch or more. Throughout the year seventeen storm events equaled or exceeded one inch of precipitation in a 24 hour period. Seven months experienced multiple one-inch plus storm events and these occurred in February, March, May, June, September, October and December.

The winter season (November 2002 through April 2003) snowfall total of 83.0 inches was significantly higher than the seasonal average of 48.21 inches**.** As an indication of the severity of the winter, by mid-March an estimated snow pack in the range of 15-20 inches still covered much of the watershed (ref. U.S. Army Corps Snow Depth Chart (Right)). Snow depth measurements were discontinued throughout the northeast after 14 April due to the lack of snow.



The melting snow pack and spring rains effectively brought reservoir operating levels back to "normal status" after experiencing below normal conditions since February 2002, due to recent drought conditions. Reservoir response to springtime conditions was quick as levels rose five feet over the course of just two months (March and April).

Figure 2



	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Precipitation (in.)	3.25	4.08	4.13	3.1	5.99	6.92	1.96	5.13	6.67	4.75	2.75	4.64
Departure from Norm (in.)	-0.17	1.13	0.31	-0.70	1.91	2.96	-2.29	0.76	2.89	1.19	-1.40	0.99
Cumm. Departure (in.)	-0.17	0.96	1.27	0.56	2.47	5.43	3.14	3.91	6.80	7.99	6.59	7.59
Number of Storms >1.0 in.	1	2	2	0	2	2	0	1	2	2	1	2
64 Year Average Precip. (in.)	3.42	2.95	3.82	3.80	4.08	3.96	4.25	4.37	3.78	3.56	4.15	3.65
64 Year Minimum	0.70	0.48	0.55	0.87	0.90	1.10	0.84	0.89	0.86	0.56	0.93	0.76
64 Year Maximum	10.21	7.03	7.58	9.11	13.09	9.62	9.45	22.96	11.55	11.08	7.32	8.19
20 Percent Exceedance	4.76	3.84	5.08	5.25	5.41	5.21	5.67	6.01	6.22	5.18	5.69	5.11
80 Percent Exceedance	1.97	2.10	2.49	2.18	2.71	2.47	2.65	2.01	1.89	2.03	2.73	2.27
Snow (in.)	17.5	28	7	2.5	0	0	0	0	0	0.5	0	22

Source: DCR Yield Data, 1939-2003

STREAM FLOWS

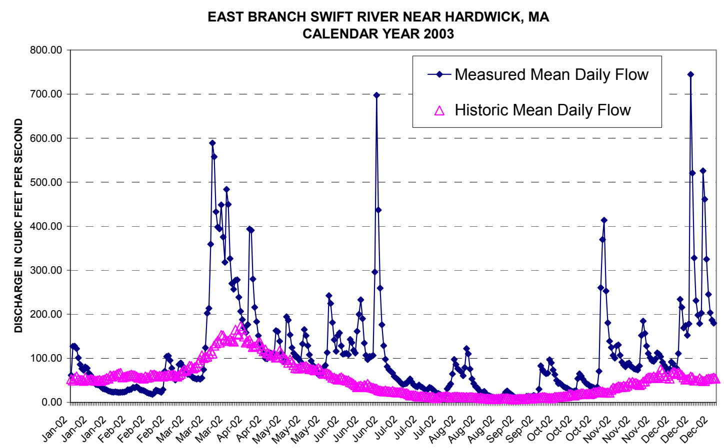
Through a cooperative agreement with the United States Geological Survey (USGS), five stream gages are actively being monitored inside the Quabbin Reservoir and Ware River watersheds. Stations include sites on the Ware River in Barre (at intake), Ware River at Barre Falls, East Branch Swift River in Hardwick, West Branch Swift River in Shutesbury, and the Swift River below Winsor Dam. Daily mean discharge values were provided by the U.S. Geological Survey, Water Resources Division. Plots of stream hydrographs and tables of daily mean values are included in the appendix of this report.

Mean Daily Discharges (2003)

Ware River at Intake Works: 209.43 cfs
Ware River at Barre Falls: 115.65 cfs
East Branch Swift River: 108.34 cfs
West Branch Swift River: 26.81 cfs

Source: U.S. Geological Survey

Watershed runoff for 2003 was generally above normal as the US Geological Survey assigned this rating to indexed stream flows for six months out of the year. Only during the month of February was stream flow rated at below normal and this was due primarily to frozen conditions. Months rated with above normal flow (i.e. exceeding the 75 percentile mark of historical records) included March, June, August, October, November and December. No new peak monthly mean flows for period-of-station records were recorded at any of the Quabbin Reservoir stations. A new peak monthly mean discharge of 215.9 cfs was established on the Ware River at Barre Falls for the month of December. Mean daily flows in the Ware River peaked at 1050 cfs on March 27 at Shaft 8, and, at 691.54 cfs on April 2 at Barre Falls Dam. On December 18 the East Branch Swift River was measured with a peak mean daily flow of 744.42 cfs. Peak mean daily flow in the West Branch Swift River was measured at 171.64 cfs on October 29.

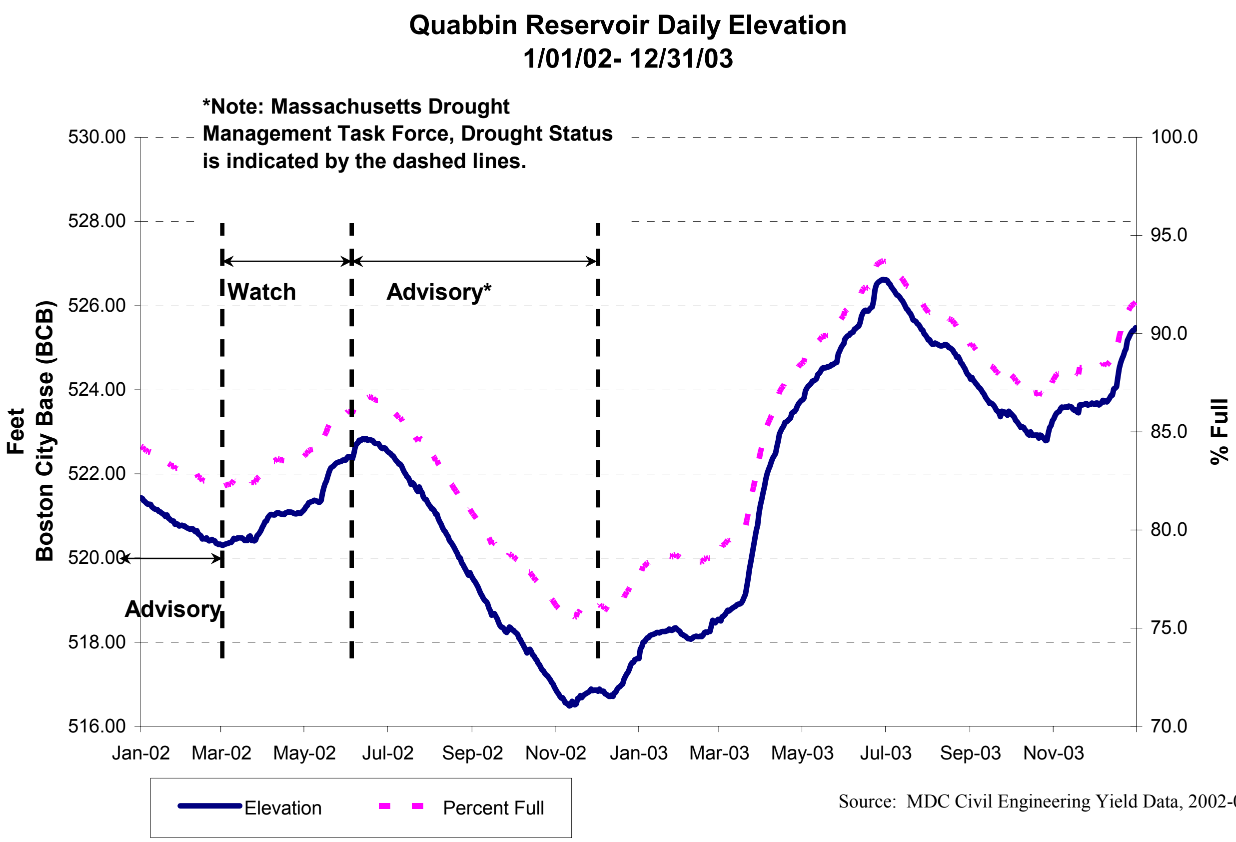


Hydrograph: East Branch Swift River, Hardwick

New minimum monthly mean flows for period-of-station records were recorded in the months of February and July. In February, a new minimum monthly mean discharge of 12.5 cfs was established on the West Branch Swift River. In July, a new minimum monthly mean discharge of 36.1 cfs was established on the Ware River at Barre Falls. At all stations minimum mean daily flows occurred between September 1-13 and were measured between zero (Ware River at Barre Falls) and 9.30 cfs (Ware River at Intake).

RESERVOIR CONDITIONS

Quabbin Reservoir storage capacity began 2003 at 77.5% full and ended at 91.60% full. The maximum reservoir elevation was recorded at 526.62 feet (Boston City Based) on June 29. The minimum elevation of 517.61 feet was recorded on Jan 1. The reservoir delivered on average 8.3 million gallons of water per day (MGD) to the Chicopee Valley Aqueduct service area over the course of 365 days. During the 177 days that water was transferred to Wachusett Reservoir, flow entering the Quabbin Aqueduct averaged 235.1 MGD. A total of 41,618.7 MG was transferred to the Wachusett Reservoir in 2003. An additional 9,236.4 MG of water was sent downstream of Winsor Dam to maintain flows in the Swift River. To supplement Quabbin Reservoir levels a total of 16,202.8 million gallons of water was diverted from Ware River. Total diversions from Ware River increased by 212% over 2002 levels and were comparable to levels last seen following drought conditions in the late 1980's. Transfer of water from the Ware River constituted 14.4% of the annual yield produced by the reservoir. Ware River diversions occurred over a course of 100 days and flows averaged 162.0 MGD. In 2003, the reservoir had a net gain of 58,333 million gallons and daily elevation levels fluctuated 9.01 feet. Daily fluctuations in reservoir water level are depicted in **Figure 3** below.



Source: MDC Civil Engineering Yield Data, 2002-03

Table 1 presents general statistics on Quabbin Reservoir and its contributing watershed area and a summary of reservoir conditions over the past three years.

TABLE 1 - QUABBIN RESERVOIR FACTS AND FIGURES

FACTS ABOUT THE RESERVOIR		FACTS ABOUT THE WATERSHED	
Capacity	412 Billion Gals	**Watershed Area**	120,000 acres
Surface Area	24,000 acres	**Land Area**	96,000 acres
Length of Shore	118 miles	**MDC Owned Land**	53,000 acres
Maximum Depth	150 feet	**% MDC Owned**	55%[1]
Mean Depth	45 feet	**Forested Lands**	83,235 acres
Surface Elevation	530 feet	**Wetlands**	5,289 acres
Year Construction Completed	1939	**Avg. Reservoir Gain From 1" of Precipitation**	1.6 Billion Gallons

Calendar Year:	**2003**	**2002**	**2001**
2001 Maximum Reservoir Elevation (ft)	526.62 on June 29	522.84 on June 13 & 15	528.53 on May 5
2001 Minimum Reservoir Elevation (ft)	517.61 on January 1	516.48 on May 5	521.46 on December 31
Total Diversions to Wachusett Reservoir	41,618.7 MG (177 days:235.1 MGD)	60,108.8 MG (269 days: 224 MGD)	62,447.8 MG (294 days: 212.4 MGD)
Total Diversions to CVA	3,029.6 MG (365 days: 8.3 MGD)	3,161.2 MG (365 days: 8.7 MGD)	3,296.7 MG (365 days: 9.0 MGD)
Ware River Transfers	16,202.8 MG (100 days: 162 MGD)	5,246.2 MG (71 days: 73.9 MGD)	4,122.7 MG (11 days: 4/12-4/22)
Spillway Discharges	NONE	NONE	2,537.3 MG (93 days: 4/16-7/20)
Total Diversions to Swift River	9,236.4 MG (25.3 MGD)	12,467.9 MG (34.2 MGD)	18,334.2 MG (50.2 MGD)
Reservoir Ice Cover	≈100% cover: January 21 through April 7 (76 days).	Full reservoir ice cover not obtained.	≈100% cover: January 23 through March 25 (61 days).

Notes: Source: MDC Civil Engineering Yield Data, 2003

1.) Excludes reservoir surface area.

2.) (….) – Denotes number of days and average daily flow.

2.0 WATER QUALITY MONITORING PROGRAM

Water quality monitoring is an important component of the Division's watershed control program, whose primary goal is to provide a safe drinking water supply. Water quality monitoring is driven both by the need to satisfy regulatory mandates and for general purposes of gathering information to be used for source water characterization and specific watershed management decisions (e.g. gull control). Routine monitoring of tributaries and the reservoir includes analysis for temperature, pH, alkalinity, dissolved oxygen, specific conductance, turbidity, color, total coliform bacteria and fecal coliform bacteria. **Table 2** below lists the equipment and laboratory methods employed by Quabbin laboratory staff.

Table 2. QUABBIN LABORATORY: ANALYTICAL AND FIELD METHODS

PARAMETER	STANDARD METHOD (SM)[1]
Turbidity	SM 2130 B
pH	SM 4500-H Hydrolab Data Sonde 4a, Orion 811 meter
Alkalinity	SM 2320 B (low level)
Color	SM 2120 B
Conductivity	HACH DREL/5 meter Hydrolab Data Sonde 4a
Temperature	YSI Model 57 DO Meter Hydrolab Data Sonde 4a
Dissolved Oxygen	YSI Model 57 DO Meter Hydrolab Data Sonde 4a
Total Coliform	SM 9222B
Fecal Coliform	SM 9222
Escherichia coli (E. coli)	EPA Modified mTEC Agar Method

[1]Standard Methods for the Examination of Water and Wastewater, 20th Edition

In CY 2003, Quabbin laboratory staff processed and analyzed 2,669 source water samples. Of the 2,669 samples; 1,827 were collected for microbial analysis and 842 samples were collected for chemical analysis. Nearly 9,000 individual analyses were performed on these samples and nearly half were physiochemical analyses performed at Quabbin laboratory. The remaining analyses were split between physiochemical measurements taken in the field (1,506) and bacterial analyses performed at the Quabbin laboratory (2,870). All records are maintained in permanent bound books and in a digital format (Mircosoft Access database). Quality control records are maintained on permanent bound books.

2.1 Measurement Units

Chemical concentrations of constituents in solution or suspension are reported in milligrams per liter (mg/L) or micrograms per liter (μg/L). Milligrams per liter is a unit expressing the concentration of chemical constituents in solution as weight (milligrams) of solute per unit of volume of water (liter).

One milligram per liter is equivalent to 1,000 micrograms per liter. Bacteria densities are reported as number of presumptive colony forming units per 100 milliliters of water (CFU/100 mL). The following abbreviations are used in this report:

CFS	Cubic feet per second
CFU	Colony forming unit
MGD	Million gallons per day
NTU	Nephelometric turbidity units
PPM	Parts per million (1 mg/L = 1 PPM)
CU	Color units
TC	Total Coliform
THMFP	Trihalomethane formation potential
TKN	Total Kjeldahl nitrogen
µS/cm	Microsiemens per centimeter
µmhos/cm	Micromhos per centimeter (1 µmhos/cm = 1 µS/cm)

2.2 2003 LABORATORY CHANGES

Two significant changes were made to the Quabbin laboratory monitoring program in 2003. Changes were necessary responses to changes in staffing levels, budgetary constraints and a general shift in laboratory priorities.

1) The laboratory discontinued laboratory analysis of iron and hardness. Since 1990, these parameters had been monitored at all routine stations on a quarterly basis. Prior to 1990 analysis was performed biweekly. The purpose of the recent change was due to a reprioritization of limited staff time.

2) Sample collection was discontinued at site 212-X, located at the mouth of Hop Brook. Site 212-X had originally been added in April 1992 to monitor improvements in water quality below active beaver residing at the upstream station 212. In 2003, beaver have re-occupied the upstream reaches and have now constructed a dam both upstream and immediately downstream of site 212.

2.3 SOURCE WATER QUALITY MONITORING

SWTR Source Quality Criteria

- Coliform Limits: Six-month, running compliance period in which fecal coliform ≤20/100 mL in 90% of samples.
- Turbidity Limits: Before disinfection, turbidity not to exceed 5 NTU* based on sampling at 4-hour intervals.
- *MA DEP has set a performance standard of 1 NTU.

In 1989, the U.S. Environmental Protection Agency promulgated the Surface Water Treatment Rule (SWTR) to ensure that public water supply systems using surface waters protect against waterborne diseases that may result from exposure to viruses and microbial pathogens such as *Giardia lamblia*. The SWTR in effect requires filtration by every surface water supplier unless strict source water quality criteria and watershed protection controls can be met. Source water quality compliance relies on a surrogate parameter, turbidity, and an indicator organism, fecal coliform (FC) bacteria, to provide a relative measure of the sanitary quality of the water. Bacteria monitoring from a point upstream of treatment must be performed at a minimum of five days a week and continuous turbidity monitoring is acceptable. Additionally, the DCR monitors water quality at three other source water stations and three "finished" water stations located on the CVA service line. **Table 3** lists the locations and sampling frequencies of the seven source water and quality assurance sample stations.

Table 3 – 2003 Source Water Compliance and Quality Assurance Sample Stations		
Station	***Location***	***Frequency***
(201) Winsor Power Station	Building tap located on Chicopee Valley Aqueduct prior to disinfection.	Daily – Constitutes AM collection Monday through Thursday. Sampling is increased with an additional PM sample collected seven days a week during phases of the *Gull Control Program.*
(206) Shaft 12 shoreline	Quabbin Reservoir shoreline beside Shaft 12 intake building	Weekly
(101) Ware River at Shaft 8	Bank of Ware River immediately downstream of Shaft 8 intake works building.	Biweekly
Shaft 11A	Quabbin Aqueduct outlet on Quabbin Reservoir shoreline, east of baffle dams.	Weekly during Ware River diversions.
Ludlow Monitoring Station (LMS)	Chicopee Valley Aqueduct, Route 21 Ludlow.	Daily – AM collection seven days a week.
Nash Hill	Chicopee Valley Aqueduct, storage facility.	Daily – Constitutes AM collection Monday through Friday or as often as possible.
Chicopee	Chicopee Valley Aqueduct, Chicopee Water Treatment Plant.	Site serves as an alternate to Nash Hill and thus is sampled infrequently.

A water tap located inside the Winsor Power Station, at the base of Winsor Dam in Belchertown serves as the source water sample site for SWTR compliance purposes. The site, referred to as Site 201, is representative of "raw" water entering the Chicopee Valley Aqueduct from approximately seventy feet below the surface of Quabbin Reservoir. Compliance with the SWTR bacteria standard stipulates that raw water levels cannot exceed 20 FC colonies per 100 mL in more than 10% of the samples taken in a six-month period. The Quabbin Reservoir has fully met the SWTR Source Quality criteria since June 1991, thanks in large part to a successful Gull Control Program administered by the DCR. Historic data from Site 201 over the 1990-1999 period show that FC bacteria levels are very low averaging 1 colony forming unit (CFU) per 100 milliliters (mL). However, a seasonal presence of a high number of gulls roosting in the vicinity of the CVA intake has resulted in occasional FC spikes that approach, and in some cases exceed the 20 FC colonies per 100 mL limit. In 2003, FC levels monitored daily at Site 201 averaged less than one colony forming unit per 100 mL and FC was absent in 89.3% of the 374 raw water samples collected. In 2003, FC levels spiked to a high of 9 CFU per 100mL measured on January 10. The next highest FC level was 7 CFU per 100mL detected on January 11. Both samples were collected at a time when daily gull numbers were relatively modest (less than 200 birds), but, strong north winds prevented launching of boats and likely helped transport bacteria from the northern roost site to the CVA intake

The Massachusetts Department of Environmental Protection (DEP) turbidity standard for unfiltered water supply systems is a maximum of 1.0 NTU; the EPA standard is a maximum of 5.0 NTU. Turbidity is monitored for compliance purposes using MWRA's online, continuous turbidimeter located at the Ware Disinfection Facility. The DCR monitors turbidity at Site 201 weekly for assessment purposes only. In 2003, turbidity levels at Site 201 remained well below the DEP standard of 1 NTU. Turbidity levels averaged 0.29 NTU and there were no significant spikes as the maximum level was measured at 0.45 NTU on 9 June. Occasional fluctuations may be attributed to algae dynamics and extreme wind events.

DCR also monitors Site 201 biweekly for *Cryptosporidium.* and *Giardia Lamblia*, for the purpose of maintaining an historical data set. The data set was formally established in 1996 in response to the EPA's promulgation of the Information Collection Rule. *Cryptosporidium spp*. oocysts and *Giardia spp*. cysts are of concern because of their low doses of infectivity, relatively high resistance to disinfectants, and prolonged life-cycles. Both pathogens have been associated with widespread, waterborne outbreaks of gastrointestional disorders such as diarrhea, cramping and nausea. Sample collection and analysis follows protocols established for the immunoflourescence assay method (IFA Method) under the EPA's 1996 Information Collection Rule. In 2003, twenty-four samples were collected by DCR staff and sent to the Erie County Water Authority of New York for analysis. All 2003 results were below detection limits and a target sample volume of 100 gallons was achieved each time. Detection limits ranged from 0.53 to 1.06 cysts per 100 liters. In 2003, the EPA proposed future treatment technique requirements specifically for *Crptosporidium* that will look to establish log inactivation levels based on mean levels of oocysts. Under the current proposal of the Long Term 2 Enhanced Surface Water Treatment Rule (EPA, 2003), the CVA system supply will be required to use a minimum of two primary disinfectants and monthly monitoring for cryptosporidium will be required for at least another two years.

The DEP requires that total coliform bacteria and chlorine residual be tested regularly along the CVA service supply line downstream of the Ware Disinfection Facility. Total coliform (TC) bacteria and chlorine residual serve as relative measures of the sanitary quality of the "finished" water and as a gauge of the treatment efficiency. At a minimum, samples are collected daily from Site 201 (raw water source) and the Ludlow Monitoring Station, located approximately eight miles downstream of the Ware Disinfection Facility. Other downstream "finished" water sites are located at the Nash Hill water storage tank and the Chicopee Water Treatment plant (alternate site). In 2003, the Quabbin Laboratory performed TC bacteria analysis on 486 finished water samples collected by MWRA personnel. All tests were negative for the presence of bacteria.

Raw water TC bacteria levels measured at Site 201 have historically been low with occasional exceedances of the 100 CFU per 100 mL standard. However, in recent years, as shown in **Figure 4**, elevated TC levels have been measured over an extended period from mid-July to late-October. In 2003, TC levels at Site 201 averaged above the 100/100mL standard for a period of 129 days

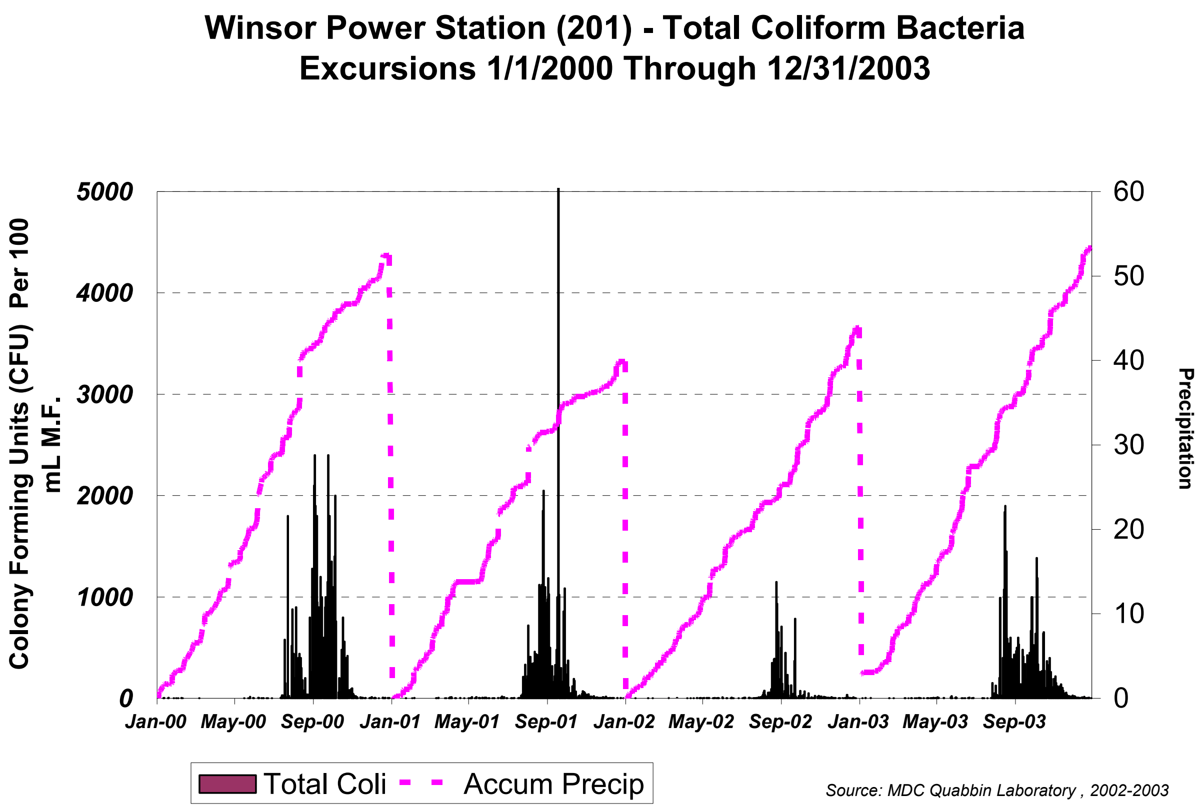


Figure 4

beginning on August 6 and continuing until December 12. During this "excursion" period, TC levels averaged 279 CFU/100 mL. In contrast, 201 TC levels during the non-excursion period averaged 3 CFU/100 mL. In 2003, the maximum TC concentration measured at Site 201 reached 1900 CFU/100mL on August 17.

Lee (2004) investigated meteorological and TC data to document correlations between the two to help better understand the dynamics behind this recent trend. Lee reported that total coliform concentrations at Site 201 were positively correlated with tributary total coliform concentrations, temperature, wind intensity and solar incidence. Statistical analysis indicated that total coliform concentrations lagged these metreorological/environmental factors by 0 to 8 months. Lee (2004) also compared meteorological data back to 1996: noting that during excursion years water and air temperature were significantly higher in the winter and the summer, while total rainfall and water yield were significantly lower in January and October. Wind intensity (as wind movement from the north) was also significantly higher in the summer of excursion years. The statistical significance of wind and of apparent lag times suggest that reservoir transport dynamics are likely a factor in TC excursions, but, its role is poorly understood at this time. Additional reservoir transect sampling might offer clues as to the transport dynamics of high inputs of tributary TC loads.

Table 4 summarizes water quality data collected by DCR at the three source water stations monitored in 2003. Results show that water quality at the two reservoir stations have fully met SWTR water quality criterion and that the water has low bacteria, low turbidity and remains a reliable and stable source of clean, safe water. Although FC bacteria levels were higher at the Ware River station, the levels are relatively low and the greater degree of variability among all parameters is expected in the river environment

Monitoring performed weekly at Shaft 12 (Site 206) in Hardwick is used to characterize the quality of water entering the Quabbin Aqueduct. Source water quality monitoring stipulated under the SWTR is not required at this location because Quabbin Reservoir water "daylights" to Wachusett Reservoir before completing its 65 mile journey to the metropolitan Boston area. Similar to Site 201, water quality at Site 206 is characterized by weekly monitoring for total coliform bacteria, fecal coliform bacteria, turbidity, pH, alkalinity, specific conductance and color (quarterly). Despite differences in sample location, water quality at Site 206 is very similar to that being withdrawn from Site 201. Site 206 is sampled as a grab sample taken from the surface of the water by the shore of the intake building. The shoreline sample location has a greater potential to detect contamination caused by localized shore activities, particularly a migrant geese population. In 2003, fecal coliform bacteria levels averaged less than 1 CFU per 100 mL and turbidity was low averaging 0.29 NTU.

Table 4. Summary of Conventional Water Quality Parameters for Quabbin Reservoir Source Water Monitoring Stations

Source: 2003 Quabbin Laboratory

Parameter	*QuabbinReservoir Site 201 CVA Intake*		*QuabbinReservoir Site 206 Shaft 12*		*Ware River at intake works Shaft 8*	
	Range	*Avg.*	*Range*	*Avg.*	*Range*	*Avg.*
Total Coliform Bacteria (CFU/100mL)	0-1,900	101	0-214	21	73-1,200	410
Fecal Coliform Bacteria (CFU/100mL)	0-9	<1	0-3	<1	0-106	21
Turbidity (NTU)	0.2-0.45	0.29	0.2-0.82	0.29	0.45-4.0	1.45
Color (CU)†	5-10	6.7	7-12.5	10	55-100	73
pH	6.33-7.32	6.69	5.62-7.3	6.81	5.75-6.81	6.24
Alkalinity (mg/L)	3.5-5.3	4.5	1.4-5.9	4.4	2.4-8.3	5.08
Specific Conductance (microhms per cm)	40-50	47.6	40-55	49	70-130	96
Dissolved Oxygen (mg/L)	8.73-16.3	11.81	6.38-15.6	10.6	7.4-15.9	11.28
†Color was monitored on a quarterly basis in 2003.						

Staff collects grab samples for physiochemical and bacterial analysis biweekly on the Ware River below the intake works structure in Barre (also referred to as Shaft 8 or Site 101). Like Shaft 12, water quality monitoring at this location is not stipulated under regulatory mandates but is performed for assessment purposes. Bacteria and turbidity levels monitored at this location are generally low, but, because of the stream environment levels have a high degree of variability unlike those of the two reservoir stations. Under the authority granted by chapter 375 of the Acts of 1926, the DCR is limited in the diversion of the water from the Ware River to a period from October 15 to June 15, and at no time is diversion allowed when the flow of the river at the diversion works is less than 85 MGD. During the allowable diversion period in 2003, fecal coliform averaged 8 CFU/100 mL and turbidity levels averaged 0.85 NTU. In contrast, non-diversion fecal coliform levels averaged 47 CFU/100 mL and turbidity levels averaged 2.5 NTU. These results show a notable improvement in water quality during the allowable diversion period.

The Quabbin Aqueduct outlet at Shaft 11A, located on the shore of Quabbin Reservoir in Hardwick, is sampled only during times of active diversion. In 2003, Shaft 11A was sampled on 16 occasions. Recognizing the conspicuous differences between reservoir water and Ware River water, a study was undertaken in the spring of 2003 in an attempt to "trace" the influence of Ware River water on the reservoir. Conductivity was chosen as a study parameter because it is a conservative parameter, *i.e.*, it does not decay over time, and any measured changes are due to mixing with water of different conductivity (dilution), and because Ware River conductivity is almost twice Quabbin Reservoir conductivity and hence can easily be traced. It should be noted that the construction of baffle dams in

Quabbin Reservoir east of Shaft 12 intake were designed to mitigate any negative effects from Ware River water by forcing water to travel north roughly 5 ½ miles before reaching the main body of the reservoir. For a period of six weeks staff collected weekly profiles of temperature and conductivity at six stations located throughout the reservoir's eastern basin. Weekly sampling began on April 16 (shortly after ice-out) and ended on June 6. The six monitoring sites are depicted in **Figure 5**.

Shortly after ice-out, profiling results on April 16 indicated that conditions up to Sunk Pond (6705 meters away from the Ware River inlet at Shaft 11A) were fully mixed and isothermal. Specific conductance results displayed as a function of distance away from the Ware River inlet at Shaft 11A are shown in **Figure 6.** The mixing length of the combined flows, displayed graphically in Figure 6, is based on the extent of uniform conductance levels and is estimated to be approximately 6,700 meters. By April 16, combined flows from the Ware River and East Branch Swift River had totaled 17,205.2 MG. For comparison purposes, GIS staff estimated the volume inside the entire eastern basin below the "pass" using 12,400 elevation points digitized off of the original Quabbin Reservoir Topographical Sheets. The estimated volume inside of the basin contained by the "pass" by Site A2 on 16 April was 22,270 MG. Theoretically, based on a simple mass balance, in-reservoir specific conductance concentrations of the "mixture" were estimated at 62 µs/cm. Actual measurements at Sunk Pond were uniform from top to bottom and averaged 65 µs/cm. This rough calculation supports the theory that incoming Ware River diversions and East Branch flows became fully mixed with reservoir water and simply displaced approximately 14.1 billion gallons that exited the basin.

Fully mixed conditions remained unchanged until the onset of thermal stratification. Beginning on May 7 conductivity changes with depth were most apparent and corresponded with thermal partitions setting up within the water column. During this period there was a distinct north-to-south gradient of decreasing conductance levels inside of what would become the metalimnion zone (initially located between depths 5 to 9 meters). Between measurements made on April 28 and May 7, average conductivity levels inside the metalimnic zone decreased by 10 µs/cm at Sunk Pond, 4.7 µs/cm at Southworth Island and 1.7 µs/cm at Den Hill. In the weeks and months that followed conductance levels in the metalimnic zone continued their steady decline and eventually reached levels comparable with those measured at Site A2, located closest to the central basin of the reservoir.
It is theorized that eastern basin circulation patterns were drawing low conductivity, bulk reservoir water from points near to Site A2 and north, into undercurrents being channeled south via the metalimnic zone. These currents could have been spurred by opposing wind driven currents in the epillimnion, which would have been fueled largely by south-southwest winds. In general, conductance levels inside the metalimnion were in a state of constant flux as levels were being affected by mixing with bulk reservoir water, a sinking epilimnic zone, and molecular diffusion processes. Although not well understood, diffusion spurred by concentration gradients across the three temperate zones served as a driver for additional mixing to occur.

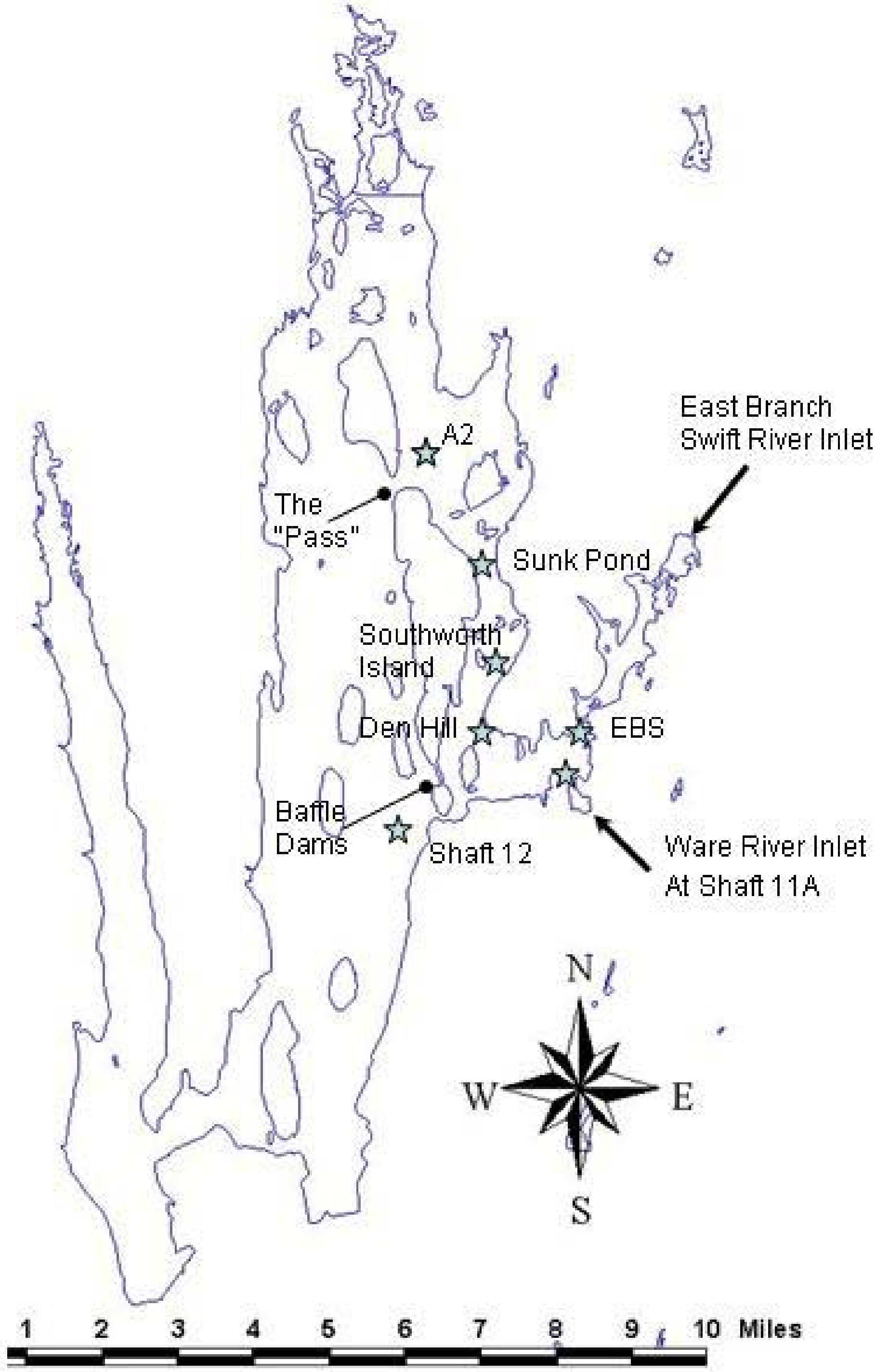


Figure 5. Diversion Study Sample Stations (Quabbin Reservoir).

Figure 6

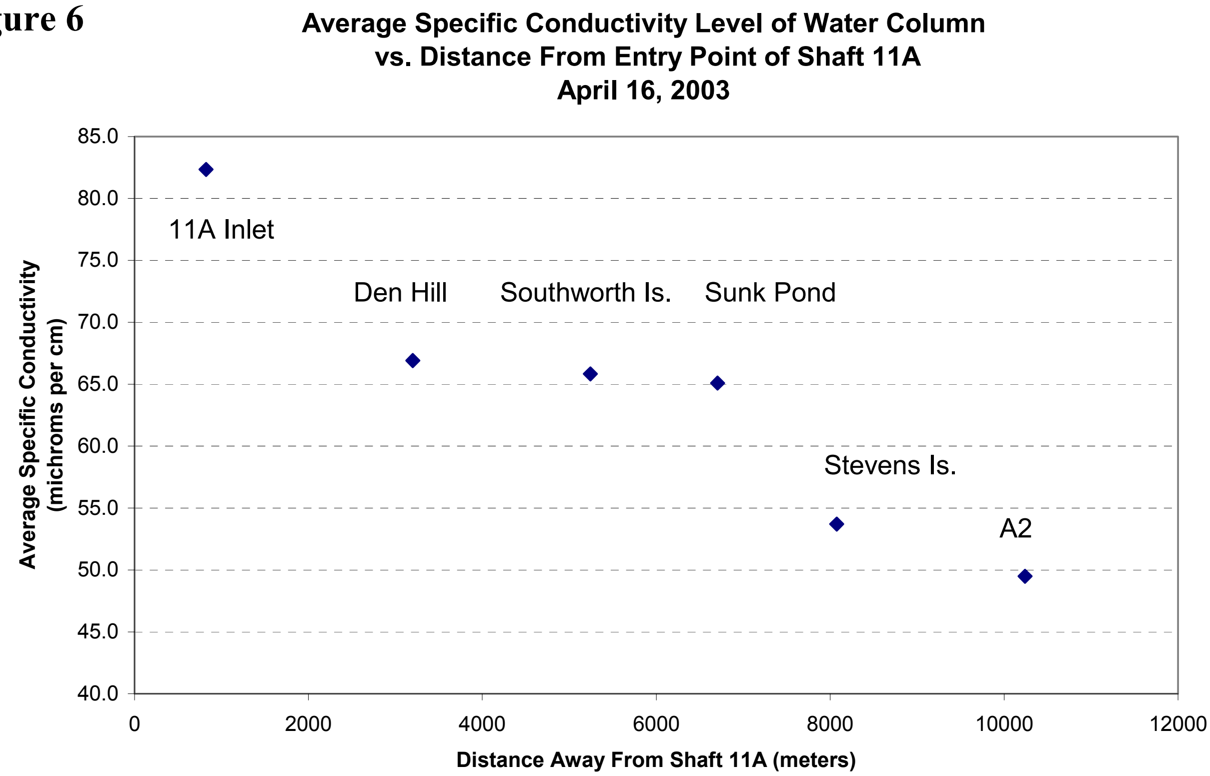
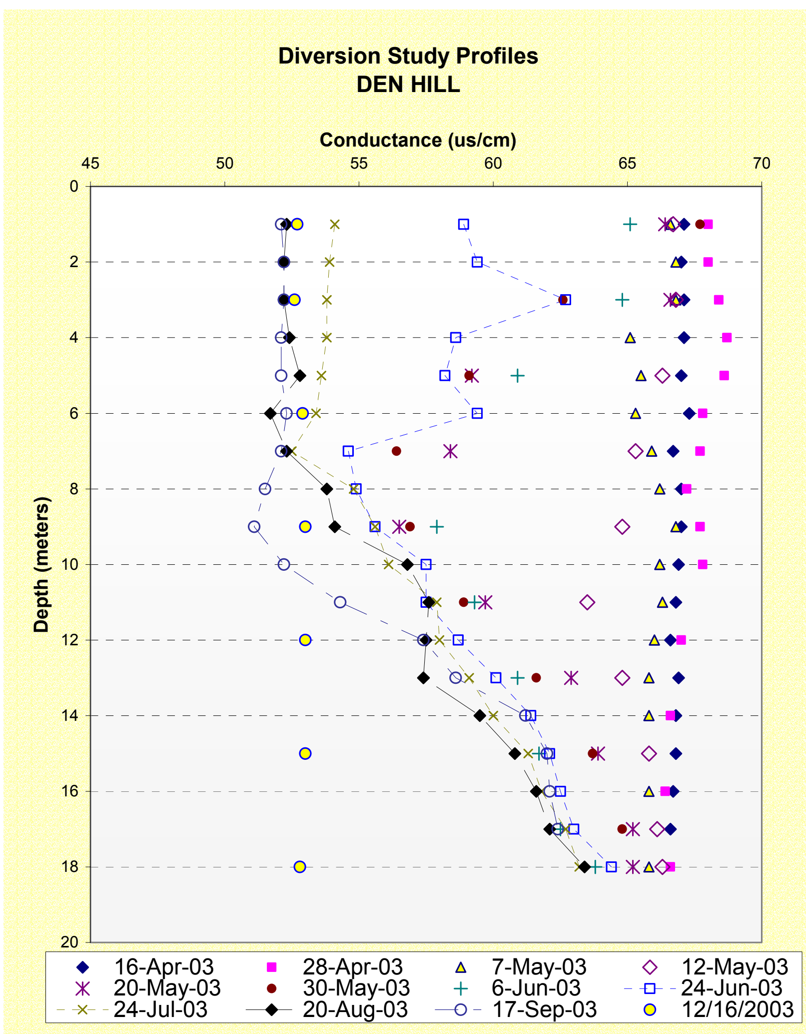


Figure 7



Profile measurements shown in **Figure 7** also reveal that changes in conductance concentrations in the epilimnion were slow to occur. It was not until July 24 that the effects of mixing circulation patterns could be seen as epilimnic water at Den Hill was fully mixed with an approximate conductance level of 55µs/cm.

Dense, hypolimnic waters were least likely to change due to restrictive thermal gradients. Prior to fall-time mixing, the hypolimnic waters at Den Hill remained elevated and relatively unchanged with levels ranging between 58 to 65µs/cm. Changes in the upper layers of the hypolimnion were again being attributed to molecular diffusive processes. Fully mixed conductivity levels at Den Hill were measured slightly below 55 µs/cm on December 16.

In summary, significant increases in Ware River diversions in 2003 made it possible for measurable levels of combined Ware River and East Branch Swift River water to be seen some 6,700 meters away from the inlet at Shaft 11A. Total diversions from Ware River increased by 212% over 2002 levels and were comparable to levels last seen following drought conditions in the late 1980's. The lateral extent of mixing is largely a factor of tributary input volumes. The basin is designed with the ability to mitigate potential impacts of higher contaminant levels found in eastern tributary inputs through the processes of complete mixing and dilution.

2.4 TRIBUTARY WATER QUALITY MONITORING

Monitoring of tributary water quality is not required by the SWTR or other regulations but does serve to establish a baseline of water quality data from which trends may serve to identify subwatersheds where localized activities may be adversely impacting water quality. Each station is sampled biweekly (happening once every two weeks) with sampling runs alternating between the two watersheds. Samples are collected by hand at the start of each work week regardless of weather conditions thereby providing a good representation of various flow conditions and pollutant loadings. Temperature and dissolved oxygen are determined in the field using a YSI Model 57 dissolved oxygen meter.

Water quality results from biweekly sampling conducted on twenty tributary streams and seven ponds located throughout the watershed are profiled in **Table 7**. **Tables 5 and 6** list subwatershed characteristics for each of the twelve Quabbin Reservoir and seventeen Ware River watershed monitoring stations that comprise the tributary monitoring network. Locations of water quality monitoring stations are depicted in **Figures 8 and 9**. A more detailed discussion and analysis follows for each specific water quality parameter.

Table 5

Quabbin Reservoir Tributaries: 2003 Sampling Sites

Tributary	DCR Sample Site #	*Sample[1] Frequency*	*Basin Characteristics*		
			Drainage Area (sq. miles)[2]	% Wetland Coverage[3]	% DCR Owned Land[4]
East Br. of Swift River @ Rt. 32A	216	BW	30.3	10.4%	1.7%
West Br. of Swift River @ Rt. 202	211	BW	12.4	3.4%	33.0%
Middle Br. of Swift River @ Gate #30	213	BW	9.14	8.1%	22.7%
East Br. of Fever Brook @ West Road	215	BW	4.15	11.5%	12.3%
West Br. of Fever Brook @ Women's Fed.	215A	BW	2.69	8.9%	18.4%
Hop Brook @ Gate 22	212	BW	4.52	2.5%	32.0%
Rand Brook @ Rt. 32A	216B	BW	2.42	9.9%	22.7%
Atherton Brook @Rt. 202	211A	BW	1.83	3.2%	36.0%
Cadwell Creek @ mouth	211BX	BW	2.59	3.3%	98.0%
Gates Brook @ mouth	Gates	BW	0.93	3.2%	100.0%
Boat Cove Brook @ mouth	BC	BW	0.15	<<1%	100.0%

Notes:

[1]BW = biweekly meaning happening once every two weeks. Prior to May 1990 tributaries were monitored on a weekly basis.

[2]Source: Massachusetts Geographic Information System, Executive Office of Environmental Affairs. Latest revision 3/90.

[3]Source: DEP Wetland Conservancy Program (interpreted from 1:12000 Spring 1992-93 photos, latest revision 4/96).

[4]Source: Automated by Massachusetts Geographic Information System & MDC, latest revision 6/97.

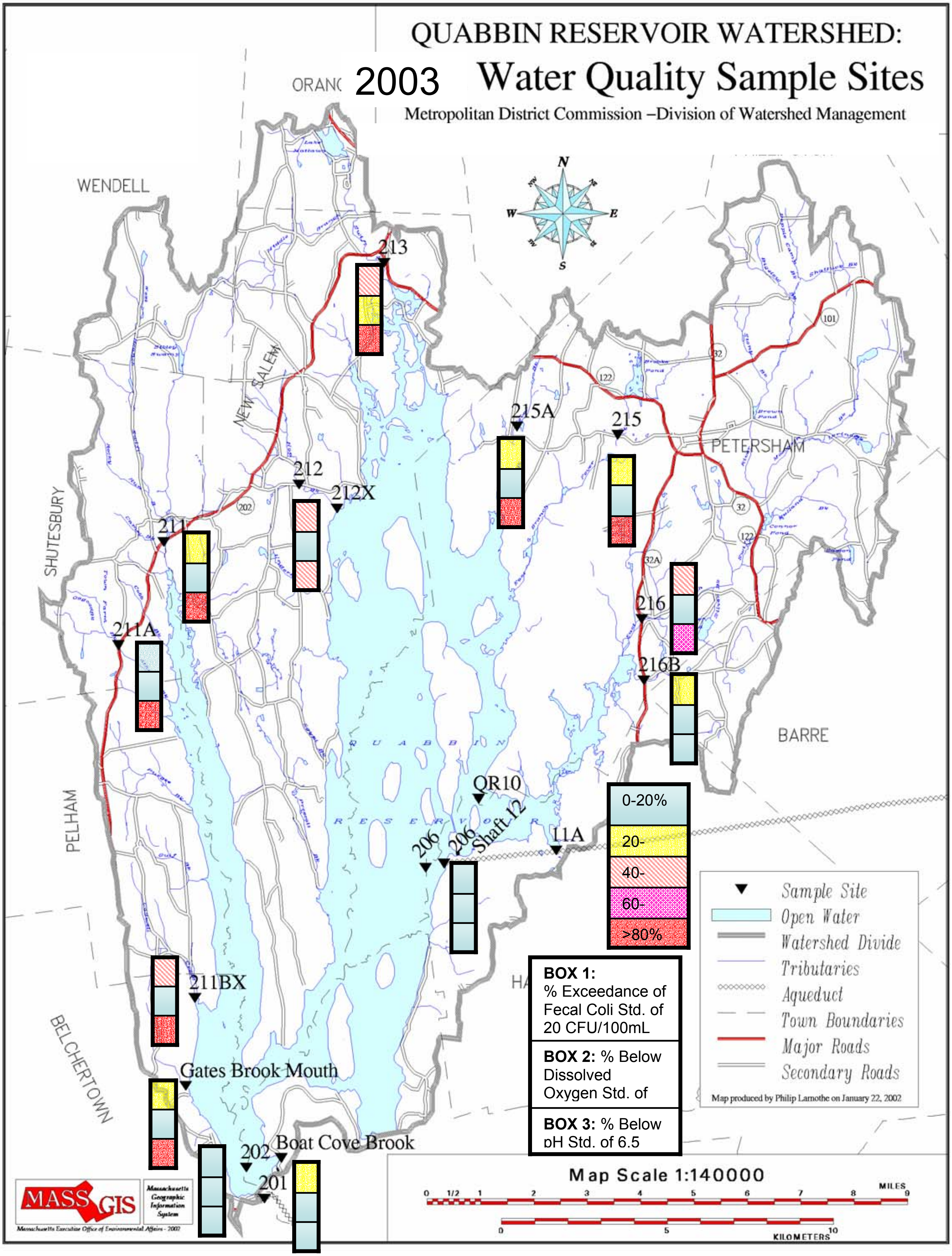

QUABBIN RESERVOIR WATERSHED:
2003 Water Quality Sample Sites
Metropolitan District Commission –Division of Watershed Management
ORANGE
WENDELL
NEW SALEM
SHUTESBURY
PELHAM
BELCHERTOWN
PETERSHAM
BARRE
213
215A
215
212
212X
211
211A
216
216B
QR10
206
206
Shaft 12
11A
211BX
Gates Brook Mouth
Boat Cove Brook
202
201
0-20%
20-
40-
60-
>80%
BOX 1: % Exceedance of Fecal Coli Std. of 20 CFU/100mL
BOX 2: % Below Dissolved Oxygen Std. of
BOX 3: % Below pH Std. of 6.5
Sample Site
Open Water
Watershed Divide
Tributaries
Aqueduct
Town Boundaries
Major Roads
Secondary Roads
Map produced by Philip Lamothe on January 22, 2002
Map Scale 1:140000
MILES
KILOMETERS
MASS GIS
Massachusetts Geographic Information System
Massachusetts Executive Office of Environmental Affairs - 2002

Table 6

Ware River Tributaries: 2003 Sampling Sites

Tributary	DCR Sample Site #	Sample Frequency[1]	Basin Characteristics		
			Drainage Area (sq. miles)[2]	% Wetland Coverage[3]	% DCR Owned Land[4]
Ware River @ Shaft 8 (intake)	101	BW	96.5	13.2%	37.1%
Burnshirt River @ Rt. 62	103	BW	18.4	11.7%	23.5%
Cannesto/Natty @ Rt. 62	104	BW	12.7	8.7%	28.0%
Ware River @ Barre Falls	105	BW	55.1	15.6%	34.5%
Parker Brook @ mouth	102	BW	4.9	9.6%	82.7%
West Branch Ware @ Rt. 62	107	BW	16.6	15.1%	44.9%
East Branch Ware @ New Boston Rd.	108	BW	22.0	16.5%	12.3%
Longmeadow Brook @ mouth	109	BW	12.2	16.5%	47.8%
Long and Whitehall Pond @ outlet	110	BW	5.4	17.8%	37.7%
Queen Lake @ road culvert	111	BW	0.7	36.8%	0%
Burnshirt River @ Williamsville Pond	112	BW	11.4	14.5%	2.5%
Natty Pond Brook @ Hale Road	N1	BW	5.5	14.0%	33.2%
Moulton Pond @ outlet	Moult Pd	BW	1.7	16.4	2.0
Brigham Pond @ outlet	115	BW	11.4	15.4	37.4
Asnacomet Pond @ outlet	116	BW	0.8	29.8	20.9
Demond Pond @ outlet	119	BW	2.3	18.2	14.2
Mill Brook @ Charnock Hill Road	121	BW	3.5	15.5	13.1

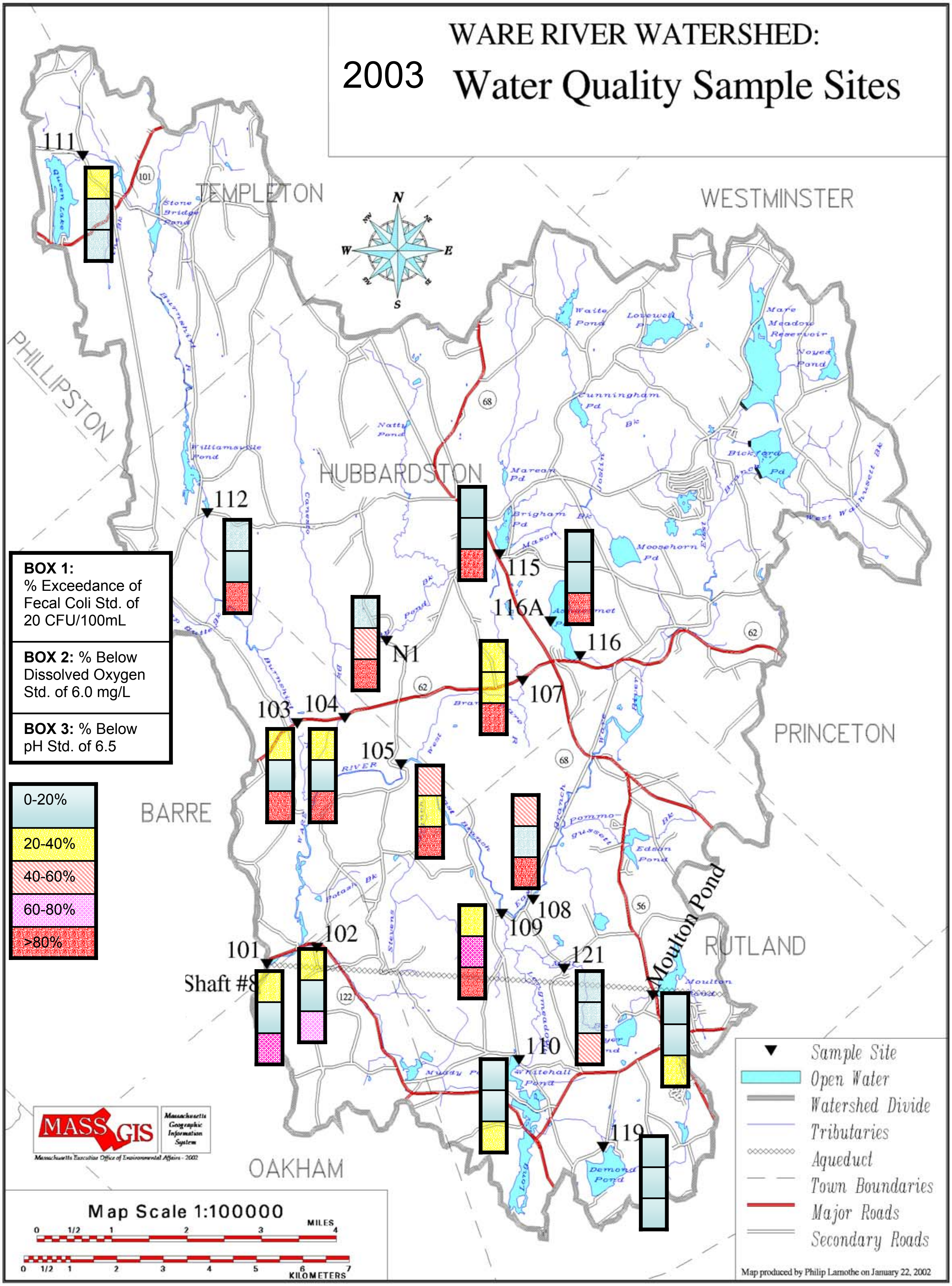
Notes:

[1]BW = biweekly meaning happening once every two weeks. Prior to May 1990 tributaries were monitored on a monthly basis.

[2]Source: Massachusetts Geographic Information System, Executive Office of Environmental Affairs. Latest rev. 3/90.

[3]Source: DEP Wetland Conservancy Program (interpreted from 1:12000 Spring 1992-93 photos, latest revision 4/96).

[4]Source: Automated by Massachusetts Geographic Information System & MDC, latest revision 6/97.



2003
WARE RIVER WATERSHED:
Water Quality Sample Sites
BOX 1: % Exceedance of Fecal Coli Std. of 20 CFU/100mL
BOX 2: % Below Dissolved Oxygen Std. of 6.0 mg/L
BOX 3: % Below pH Std. of 6.5
0-20%
20-40%
40-60%
60-80%
>80%
TEMPLETON
WESTMINSTER
PHILLIPSTON
HUBBARDSTON
BARRE
PRINCETON
RUTLAND
OAKHAM
111
112
115
116A
116
N1
107
103
104
105
108
109
121
101
102
Shaft #8
Moulton Pond
110
119
Queen Lake
Stone Bridge Pond
Williamsville Pond
Natty Pond
Waite Pond
Lovewell P
Mare Meadow Reservoir
Noyes Pond
Cunningham Pd
Bickford Pd
Brigham Pd
Moosehorn Pd
Edson Pond
Whitehall Pond
Demond Pond
Muddy Pd
RIVER
Sample Site
Open Water
Watershed Divide
Tributaries
Aqueduct
Town Boundaries
Major Roads
Secondary Roads
MASSGIS
Massachusetts Geographic Information System
Massachusetts Executive Office of Environmental Affairs - 2002
Map Scale 1:100000
MILES
KILOMETERS
Map produced by Philip Lamothe on January 22, 2002

Table 7. Summary of Conventional Water Quality Parameters for Quabbin Reservoir Tributaries, Ware River Tributaries and Ware River Ponds

Source: 2003 Quabbin Laboratory

Parameter	*QuabbinReservoir Tributaries*		*Ware River Tributaries*		*Ware River Ponds*	
	Range	***Avg.***	***Range***	***Avg.***	***Range***	***Avg.***
Total Coliform Bacteria (CFU/100mL)	7-15,000	870	47-7,000	535	0-2,000	176
Fecal Coliform Bacteria (CFU/100mL)	0-700	46	0-170	18	0-284	11
Turbidity (NTU)	0.1-4.0**	0.81	0.25-5.5	1.3	0.2-3.0	0.82
Color (CU)†	7.5-100	54.8	25-140	72	10-200	48
pH	4.9-7.1	6.17	5.2-6.8	6.10	5.5-7.1	6.5
Alkalinity (mg/L)	1.4-13.9	6.17	1.8-24.3	5.7	2.1-16.6	7.1
Specific Conductance (microhms per cm)	20-190	78.6	55-350	112	30-470	128
Dissolved Oxygen (mg/L)	3.75-17.2	10.75	0.4-16.6	9.4	2.9-17.2	10.0

**Sample result of 15.0 NTU measured at Hop Brook on June 23 omitted from statistical calculations.
†Color was monitored on a quarterly basis in 2003.

<u>Coliform Bacteria</u>

Biweekly monitoring of tributary coliform bacteria levels is not a requirement of the SWTR, but, serves as a tool to identify subbasin areas requiring special attention for watershed management activities. Coliform bacteria may be introduced to the stream environment by contact with soil, living or decaying plants, animals, and fecal excrement. The coliform group of bacteria may be differentiated between the total coliform group and the fecal coliform group by using selective culturable media and incubation temperatures. The Quabbin laboratory utilizes the membrane filter technique described in Standard Methods for the determination of both coliform groups. This technique involves the filtering of an appropriate sample volume through a 0.45 µm, gridded membrane filter, placing the filter on culturable agar in a petri dish and incubation under controlled temperature conditions.

Total coliform bacteria organisms are the umbrella group of bacteria utilized in the water supply field as an indicator of water's sanitary quality. The total coliform organism in itself is not pathogenic and is native to soil and decaying vegetation, making it ubiquitous in the environment. Geldreich (1968) and others have been critical of its use for environmental monitoring citing little sanitary significance because of its widespread occurrence in nature and their often poor correlation with that of pathogenic microorganisms (Long et al., 2002). Because of this the total coliform bacteria levels in DCR monitoring stations have not traditionally been used as "indicators" of contamination.

However, staff has observed an unmistakable trend of increasing peak TC concentrations as levels have increased from hundreds of cfu per 100 mL to thousands of cfu per 100 mL. Lee (2004) investigated this trend and was able to correlate monthly data with recent excursions from the total coliform standard measured at the Chicopee Valley Aqueduct (CVA) intake. This historical review of meteorological, water quality, and yield data provided some clues about total coliform growth and transport, but future work was recommended to investigate the speciation of the bacteria, the role of nutrients, and the relative contributions from various sources (e.g., subsurface flow, sediment, soils..).

Fecal coliform bacteria are a subset of the total coliform group, meaning that measurement of total coliform includes all measurement of fecal coliform. The fecal coliform group is present in the feces of warm-blooded animals and is distinguished in the laboratory by its ability to produce gas from a suitable culture medium at 44.5˚C. Very high concentrations of fecal coliform bacteria can be achieved when runoff comes in contact with improperly managed pet wastes, manure wastes, and seepage from faulty septic systems. Geldreich and Kenner (1969) reported bacterial densities (CFU per gram of feces shed) for cows and humans to be in the range of 230,000 to 13,000,000 CFU/g respectively. The Massachusetts Class A, inland water standard for fecal coliform is an arithmetic mean of less than or equal to 20 CFU/100mL, and, no more than 10% of representative samples shall exceed 100 CFU/100mL.

Quabbin Reservoir and Ware River tributaries generally have low fecal coliform bacteria medians. Median FC bacteria levels for the DCR monitoring stations in 2003 ranged between zero and 34 CFU/100 mL. Listed in **Table 8** are those DCR monitoring stations (13 of 30) whose average concentrations in 2003 exceeded the Class A Surface Water Quality Standard of 20 CFU/100 mL. Of those, median concentrations exceeded the 20 CFU per 100mL standard at only four stations: Ware River at Barre Falls; Middle Branch Swift River; East Branch Swift River; and, Cadwell Creek. Higher annual mean values are an indication of the fact that contamination of the tributaries is due to occasional spiking in storm influenced bacterial counts rather than sustained pollutant inputs. The highest fecal coliform bacteria concentration measured 700 CFU per 100 mL from Cadwell Creek in the summer, during a period of intense thunderstorms. Because bacteria levels can be several orders of magnitude greater during storm flows than under normal flow conditions, median values are being used to track historical trends and for comparative purposes.

Bacteria levels in streams can be several orders of magnitude greater during storm flows than under normal flow conditions. In 2003, the effects were apparent on the Quabbin Reservoir watershed as ten of thirteen sampling events, conducted between May and October were sampled under "wet" flow conditions. Wet flow conditions are described herein as days when ½ inch of rain preceded the sampling event in the 24 hour period prior to sampling or if more than one inch of rain preceded sampling in the 72 hour period prior to sampling. Comparing 2003 FC levels to historic levels from the 1990's, median FC levels were significantly higher among the Quabbin Reservoir tributaries and the reason is being attributed to the influence of storm event loadings. For the Ware River tributaries,

Table 8. Listing of Monitoring Sites with Average Fecal Coliform Bacteira Concentrations Greater Than 20 Colony Forming Units Per 100mL.

Fecal Coliform Bacteria (CFU/100mL)

Quabbin Tributaries							***Ware River Tributaries***					
Tributary	***Avg.***	***Median***	***Historic Median†***	***%>20 /100mL***	***%>100 /100mL***	***Ratio†† Wet/Dry***	***Tributary***	***Avg.***	***Median***	***Historic Median†***	***%>20 /100mL***	***%>100 /100mL***
Cadwell Creek	99	20	5	52.0%	16.0%	6.0	Ware River @Barre Falls Dam (105)	47	34	27	58.8%	17.6%
Middle Branch Swift	69	24	15	60.0%	28.0%	9.8	Queen Lake (111)	32	10	4	34.6%	11.5%
Hop Brook	54	9.5	13	46.2%	11.5%	12.5	East Branch Ware River	29	14	13	44.0%	4.0%
East Branch Swift	51	25	9	52.2%	17.4%	12.5	Longmeadow Brook (109)	25	14	16	36.8%	5.3%
East Branch Fever	39	8	3	29.2%	12.5%	7.5	Ware River @ Shaft 8	21	10	10	38.5%	3.8%
West Branch Swift	33	11	4	40.0%	8.0%	6.6						
Atherton Brook	26	6.5	1	18.2%	9.1%	2.8						
West Branch Fever	23	9	5	44.4%	5.6%	4.2						

Notes:

- The Massachusetts Class A, Surface Water Quality Standard for fecal coliform bacteria is an arithmetic mean of ≤ 20/100mL, and, no more than 10% of representative samples shall exceed 100/100mL.

† Source: Quabbin Laboratory Records – 1990 thru 1999.

†† Ratio of wet geometric mean to annual geometric mean.

storm loadings were not a significant contribution in 2003 as "wet" conditions coincided with sampling only on one occasion. This helped to explain why most Ware River tributaries fell below historic median concentrations.

The Ware River at Barre Falls (105) and the Middle Branch Swift River (213) had the highest median fecal coliform levels at 34 cfu/100mL and 24 cfu/100mL, respectively. Both sites share similar landscape attributes as both are located downstream of extensive deep marsh habitats where shallow pools, long residence times, reduced oxygen conditions, aquatic vegetation and warmer stream temperatures might provide suitable habitat for extended survival of these microbes. Studies by Crabill *et al.* (1999) and Byappanahalli *et al.* (2003) have documented the persistence of fecal coliform bacteria in the sediments of these riparian zones. Hanes *et al*. (1965) reported that coliform bacteria survived longest when dissolved oxygen concentrations were as low as 0.4 mg/L. In these cases where survival is enhanced, microbial source tracking is made difficult and additional upstream sampling is recommended.

Beaver are suspected of having influenced bacteria levels on Cadwell Creek, Hop Brook, West Branch Fever Brook, Longmeadow Brook, Atherton Brook, and the Middle Branch Swift River. In 2003, staff identified active beaver colonies and dam building activities within ¼ mile of these sampling sites. EQ staff continues to advocate for removal of beaver located inside of the "Pathogen Control Zone" established around the CVA intake.

<u>% Wetlands</u>
While not a laboratory parameter, the amount of wetland contribution to a tributary has a significant impact on water quality, particularly in the Quabbin Reservoir watershed. Percent wetland cover in the watershed was estimated using land use classification data obtained from the interpretation Spring 1992-93 aerial photography completed as a component of the DCR/MWRA *Landuse Program*. For tributaries of the DCR monitoring network, the percentage of wetlands in the drainage area range from less than 1 to 16.5%. Several researchers such as Surballe (1992) and Lent *et. al*. (1998), have statistically demonstrated the effect of wetlands on the overall water quality in the Quabbin Reservoir watershed. More recently, Garvey et al (2000) alluded to the statistical significance of an increasing, west to east gradient observed in tributary concentrations of total organic carbon, UV_{254} absorbance, Trihalomethane formation potential (THMFP), and the nutrient nitrogen and phosphorous. The observed gradient was explained by echoing previous findings relating the significance of greater wetlands in the eastern subwatersheds of Quabbin Reservoir.

<u>Turbidity</u>
Turbidity is the relative measure of the amount of light refracting and absorbing particles suspended in the water column. Turbidity is used as an indicator of water aesthetics and as a relative measure of the water's productivity. Excessive turbidity can interfere with treatment efficiency and may be harmful to aquatic species. The Massachusetts drinking water standard is 5 NTU for source water and 1 NTU for finished water. The highest turbidity value measured in 2003 was 5.5 NTU at Natty Pond Brook on July 28. Among Quabbin Reservoir tributaries, the highest turbidity level recorded was in

the Boat Cove Brook at 4.0 NTU on 14 October. Median values among Quabbin Reservoir and Ware River tributaries were both low at 0.55 and 0.7 NTU. The median values reflect the fact that turbidity spikes are infrequent and isolated to event loadings.

<u>Color</u>

Colloidal and dissolved matter such as decaying organics and certain inorganic materials can impart color to water. In 2003, the highest levels were detected in quarterly sampling during the summer months; a time when plant decomposition rates and stream temperatures are at their highest. The tributary with the highest measurement was Moulton Pond (200 CU) on 28 July. Among the Quabbin Reservoir tributaries the West Branch Fever Brook had the highest reading at 100 CU on 18 August. Lent *et al*. (1998) showed that spatial and temporal gradients within the Quabbin Reservoir watershed were related to the extent of upstream wetland area.

<u>Temperature</u>

Temperature in the tributaries ranged between zero and 25.2˚C. The Massachusetts Class A, inland water standard for a cold-water fishery stream is a maximum of 20˚C.

<u>Dissolved Oxygen (DO)</u>

Aquatic life depends on oxygen dissolved in water for its survival. DO levels are depleted through the oxygen requirements of aquatic life, the decomposition of organic matter and the introduction of foreign oxygen-demanding substances (e.g., chemical reducing agents). Temperature, stream flow, turbulence, depth and other physical characteristics of the stream are the main drivers of re-aeration, and, thus increasing DO levels. The Massachusetts Class A, inland water standard is a minimum of 6.0 mg/L (or min. 75% saturation) for cold water fisheries. Higher life forms require a minimum of about 2 mg/L of dissolved oxygen and game fish typically require at least 4 mg/L. The availability of oxygen also governs biochemical processes that modify the chemical composition of some constituents like iron and nitrogen (USGS, 1992).

Tributary DO levels are monitored biweekly and generally experience cyclic fluctuations that reflect water temperature and the level of biological activity. DCR monitoring stations with low DO levels are characteristically those associated with large contributing wetland areas immediately upstream. These large wetland areas contribute significant loads of oxygen-demanding organic acids, increase stream residence times, and typically have higher summertime temperatures due to shallow depths and greater surface area. Examples of these environs can be found upstream of Longmeadow Brook, Middle Branch Swift, West Branch Ware, Barre Falls Dam, and Natty Pond Brook. For these monitoring stations, dissolved oxygen concentrations averaged between 5.5 and 7.9 mg/L.

Beaver are suspected of lowering DO levels at Brigham Pond, Mill Brook, West Branch Fever, and the East Branch Ware. Much like the environs of large wetland areas, beaver impoundments can increase water temperatures, have greater microbiological respiratory activity, and contain greater amounts of oxygen demanding acids as a result of decaying vegetation and plant matter. For these monitoring stations, the number of samples where the dissolved oxygen concentration measured below the 6.0 mg/L standard ranged between 4.5% and 16.7%.

Table 9. Comparison of Dissolved Oxygen Concentrations in Select Quabbin Reservoir and Ware River Tributaries

Dissolved Oxygen (mg/L))

Quabbin Tributaries				***Ware River Tributaries***			
Tributary	***Range***	***Average***	***% less than 6.0mg/L***	***Tributary***	***Range***	***Average***	***% less than 6.0mg/L***
Middle Branch Swift	3.7-13.9	7.3	28.0%	Longmeadow Brook	0.4-14.3	5.5	68.4%
West Branch Fever Brook	4.1-13.3	8.7	16.7%	Natty Pond Brook	1.7-11.3	6.0	41.7%
East Branch Fever Brook	4.9-14.4	9.2	12.5%	West Branch Ware River	0.7-15.2	7.8	34.6%
West Branch Swift River	8.2-15.3	11.4	0.0%	Barre Falls Dam (W.R.)	3.5-12.8	7.9	17.6%
East Branch Swift River	8.1-17.2	11.1	0.0%	East Branch Ware River	4.9-14.3	9.7	16.0%
Hop Brook	6.4-16.1	11.5	0.0%	Long Pond	5.0-12.3	8.8	15.4%
Atherton Brook	8.5-15.5	11.5	0.0%	Brigham Pond	2.9-17.2	10.2	7.7%
				Mill Brook	4.8-14.5	9.2	4.5%
				Moulton Pond	6.9-13.2	9.7	0.0%

Notes: (1) The Massachusetts Class A, Surface Water Quality Standard for dissolved oxygen is a minimum of 6.0 mg/L.

Low dissolved oxygen concentrations (averaged 8.43 mg/L) at the outlet of Long Pond are unexplained but consistent with historical data. In 2003, Long Pond had the highest median water temperature (13.5˚C) and the highest median specific conductance level (300 µs/cm) among Ware River ponds. Moulton Pond ranked second highest among the same categories at 11.85˚C and 190 µs/cm. Overacre et al. (2003) studied the effects of road salt on Spy Pond, located in Arlington, Massachusetts. The results indicated that in one basin the effects of salty water were of the physical nature, namely the hampering of vertical turbulent diffusion and an incomplete spring mixing. Researchers hypothesized that salt-laden bottom waters chemically stratified the water column, creating density gradients that created a barrier to complete spring mixing (and re-aeration). It is hypothesized that a DPW road salt shed located on the banks of Long Pond could be having similar localized effects. Additional data collected on the mixing dynamics of ponds located throughout the watershed might provide some clues to help explain the apparent dissolved oxygen deficit.

pH

pH (hydrogen ion activity) is the measure of the water's reactive characteristics. A drop in pH by one unit represents a ten-fold increase in acidity. A value of 7 indicates neutral water. The lower the pH the more likely the water will dissolve metals and other substances. At pH levels below 6.0, the water solubility of persistent heavy metals such as mercury is increased and are more readily metabolized by living organisms. Because mercury is eliminated from fish at a very slow rate, in time mercury levels may bioaccumulate and reach high enough levels potentially harmful to those who consume fish.

Like mercury, atmospheric deposition serves as the major pathway for strong acids to reach the reservoir. Sulfur gas emissions, a byproduct of the burning of coal and oil, react with water to form sulfuric acid, the primary source of strong acids. The National Atmospheric Deposition Program (NAPD) has established a rainfall monitoring program on Quabbin Reservoir's Prescott Peninsula since 1987. During that time the level of pH in precipitation has remained low but has been stable over the 14 year period ranging between 4.25 and 4.50.

Other watershed sources of acid include the oxidation of sulfur and nitrogen compounds and the decay of organic materials. In the soil environment, a low pH (or excess of H+ ions) can lead to the cation exchange of H+ for the macronutrients (i.e., Ca, Mg and NO_3) and the toxic metal aluminum, normally adsorbed onto soil particles. Ulrich (1980) described this leaching phenomenon as an "acid push" and showed that the condition is exacerbated in periods of reduced rainfall, when surplus H^+ (Hydrogen ion) ions become accumulated in the soil environment, are followed by wetter periods. Excessive "leaching" of macronutrients may cause soil infertility, increased stream acidity and an increase of water soluble toxins in the stream environment. Ulrich (1980) also called attention to the fact that mineralization and nitrification rates in the soil are markedly increased by extended warm and dry weather periods, and, that a similar "acid push" effect could occur as a result of the generation of H+ ions through nitrification. Scientific studies have clearly shown that an inhibited supply or hampered uptake of these macronutrients by trees can result in nutrient deficiencies that have an impact on the overall health of the forest and may ultimately lead to dieback symptoms.

The pH standard specified for Massachusetts Class A, inland water ranges from 6.5 to 8.3. In 2003, median pH levels for DCR monitoring stations ranged from 5.42 to 6.96. Tributary pH levels experience cyclic fluctuations that primarily reflect stream flow. Cyclic "highs" (i.e. higher pH) occur during low flow periods when groundwater baseflow is dominate and the effects of soil weathering processes are more pronounced due to higher soil residence times. Cyclic "lows" occur during high flow periods-in particular during the springtime snowmelt or storm events – when rapid movement of runoff to the stream results in a lower hydraulic residence time within the soil resulting in less weathering and more washing of weak organic acids released by decomposition.

Table 10. Sensitivity[1] Listing of Endangered and Critical Surface Waters
Quabbin Laboratory (2003)

pH and Acid Neutralizing Capacity (ANC reported as mg/L as CaCO3)

Quabbin Tributaries				*Ware River Tributaries*			
Tributary	***ANC Range***	***Median pH***	***ARM[1] Ranking***	***Tributary***	***ANC Range***	***Median pH***	***ARM[1] Ranking***
Gates Brook	1.4-3.8	5.42	Critical	Can./Natty (103)	2.0-4.8	5.79	Endangered
Cadwell Creek	1.6-6.0	5.75	Critical	Burnshirt (112)	1.8-5.2	5.90	Endangered
Atherton Brook	1.7-5.9	5.86	Critical	Comet Pond	3.2-4.3	6.35	Endangered
E. Branch Fever	1.9-4.7	5.60	Endangered	Brigham Pond	2.1-6.7	5.96	Endangered
M. Branch Swift	1.9-4.7	6.12	Endangered	Burnshirt (104)	2.2-6.8	6.18	Endangered
W. Branch Swift	2.2-8.2	6.09	Endangered	W. Branch Ware	2.2-9.5	5.77	Endangered
E. Branch Swift	2.4-8.9	6.41	Endangered	Parker Brook	3.3-7.7	6.35	Endangered
W. Branch Fever	2.6-9.0	5.96	Endangered	Queen Lake	4.0-6.8	6.60	Endangered
Hop Brook	3.9-12.5	6.53	Endangered	E. Branch Ware	2.8-9.3	6.13	Endangered
Rand Brook	3.8-12.2	6.70	Endangered	Natty Pond Bk	2.2-10.8	5.73	Endangered
				Longmeadow Bk	4.4-18.2	6.25	Endangered

Notes:

(1) ARM sensitivity criteria were established by the Acid Rain Monitoring Project at the University of Massachusetts, Amherst. The criteria are based on the acid neutralizing capacity (ANC) of surface water measured in April when flora and fauna are most vulnerable. Alkalinity levels are used to measure the ANC of surface water and ARM category rankings are as follows:

Critical: Alkalinity 0-2 mg/L or pH<5
Endangered: Alkalinity 2-5 mg/L
Highly Sensitive: Alkalinity 5-10 mg/L
Sensitive: Alkalinity 10-20 mg/L

Alkalinity is a relative measure of water's ability to neutralize acidic inputs, and thus is a measure of a waterbodies defense against acidification. The Massachusetts Acid Rain Monitoring (ARM) project utilizes alkalinity readings in April to categorize and rank sensitivity of waters to impacts from acid rain. In 2003, 24 of 30 DCR monitoring stations had levels below the two most sensitive categories established by the ARM project. At three stations, Gates Brook, Cadwell Creek and Atherton Brook, alkalinity levels were classified as critical. The listing of alkalinity rankings is shown in **Table 10**.

Specific Conductance

Specific electrical conductance is the measure of the ability of water to conduct an electrical current, which is dependent on the concentration and availability of mineral ions. Elevated levels may be indicative of contamination from septic system effluent, stormwater discharges or agricultural runoff. One significant source of higher levels in tributaries is chloride found in deicing salts applied to highways and local roads.

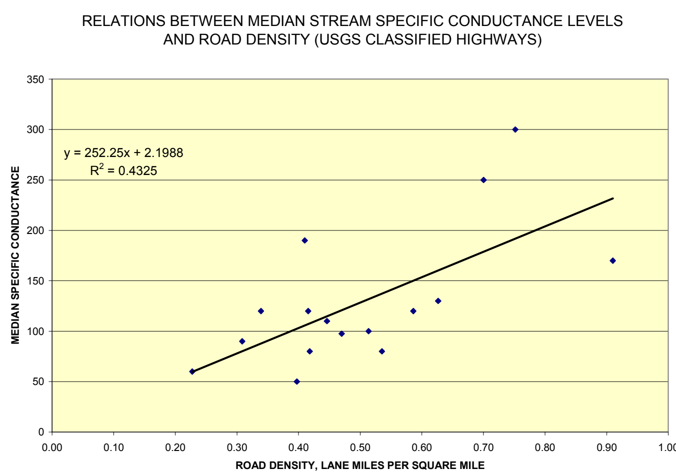


Figure 10 (Right) shows the linear regression produced by comparing mean specific conductivities from the 2003 period to USGS classified highway road densities. The data includes results from sixteen DCR-DWSP monitoring stations where specific conductance was monitored biweekly during CY 2003. All sixteen stations had higher densities of local roads than primary and secondary highways. Densities of highways ranged between 0.23 and 0.91 lane miles per square mile while local road densities ranged between 1.67 and 5.13 mi/sq. mi..

Within the Quabbin Reservoir and Ware River watersheds, there is a weak but apparent relationship between elevated specific conductance levels and the increasing density of primary and secondary highways (Figure 10). About 43 percent of the variation was accounted for by the variation in density of primary and secondary highway roads. In contrast, no clear correlation ($r^2 = 0.12$) could be identified between the total density of all roadways and median specific conductance levels. A p ossible explanation for these differences could be that many of the primary and secondary highways (as designated by the US Geological Survey) are State-maintained roads where the salt to sand ratio of deicing agents is significantly higher than ratios used on local roadways where speeds are lower, roads are narrower, and drainage systems are typically less efficient.

Sites where road salting effects are suspected of influencing heavily on elevated specific conductance levels include Moulton Pond, Long Pond, Mill Brook, Parker

Highway Road Densities of Selected Quabbin Reservoir Tributaries
(Miles of Highway Per Square Mile)

Drainage Basin	Density
Long Pond	0.75
Mill Brook	0.70
Parker Brook	0.91
Moulton Pond	0.41*
Hop Brook	0.59
East Branch Fever	0.63

*Levels most likely being influenced by proximity to nearby drainage outfall structure.

Brook, East Branch Fever and Hop Brook. At these locations, median specific conductance levels ranged between 120 and 300 µs/cm, and, density of highways ranged between 0.41 and 0.91 lane miles per square mile. The close proximity of Rutland Center to many of these sites also suggests that the additional load from wintertime salting of sidewalks and parking lots may likely be significant and might explain some of the uncertainty in the correlation to highway densities.

Examining conductance levels between 1994 through December 2003, almost all of the tributaries exhibited a trend of increasing conductivity (i.e., **Figure 11 and 12**). The only exception to this trend of increasing conductance levels was the Gates Brook tributary, which exhibited a slight decreasing trend. It is worth noting that the Gates Brook subbasin is owned almost exclusively by the DCR and is void of highways and secondary local roads. The reason for the apparent trend of increasing levels is not known but some possible explanations might be due to some recent, unique climatic conditions or the growing reliance on deicing agents by local and state highway personnel.

Climatic conditions since 1999 can be characterized by a series of extremes involving extended dry periods followed shortly thereafter by higher than normal wet conditions. As an example, Calendar Year 2000 was among the ten wettest years on record (records date back 64 years) at the DCR precipitation monitoring station in Belchertown. In the following year the start of a short term, mild drought was triggered when monthly rainfall totals for October and November ranked amongst the twelfth driest on record. This mild drought persisted throughout most of 2002 before the Drought Management Advisory Committee recommended that drought advisory levels be returned to normal on December 18, 2002. The paucity of runoff can lead to several factors that will result in increased specific conductance levels. For one, the dilution effects or the lack of during extended periods of dry weather can in effect increase in-stream concentrations of minerals even though the actual load to the stream is unchanged (i.e. simple dilution). Second, as described previously subsequent wetting of the soil environment can create an "acid push" that results in an accelerated leaching of mineral cations from the soil environment. In this particular case, the actual mineral load to the stream would be increased. Present laboratory data is limited in its ability to fully understand mineral leaching dynamics, a possible explanation for the apparent trend of rising conductance levels.

The properties of chloride, namely its biological inactivity, poor ability to precipitate, and poor ability to adsorb onto mineral surfaces, make it highly mobile in the environment. These same properties have also made it an ideal tracer for the study of flow dynamics (Hebbert *et al.,* 1979 and Broshears *et al.,* 1993). Numerous studies have linked the contamination of receiving waters with the application of deicing salts (U.S. Geological Survey, 1981 and Meyer, 1999). In work performed on the Quabbin reservoir watershed Shanley (1994) attributed a 120% increase (equaivalent basis) in chloride load to the stream due to the effects of road salting inside of the East Branch Fever Brook subbasin. Because of the conservative properties of chloride it would be expected that an increasing reliance on its use as a deicing agent would eventually be reflected in stream water chemistry. Studies have linked deicing salt application to the acidification of lakes and receiving waters via the ion exchange of sodium for the hydrogen ion (Norton et. al., 1989); increased mobility of heavy metals trapped in sediments; and, the production of anoxic conditions due to the chemical stratification of receiving waters via the introduction of heavy, restrictive density gradients of road salt runoff (Overacre, 2003).

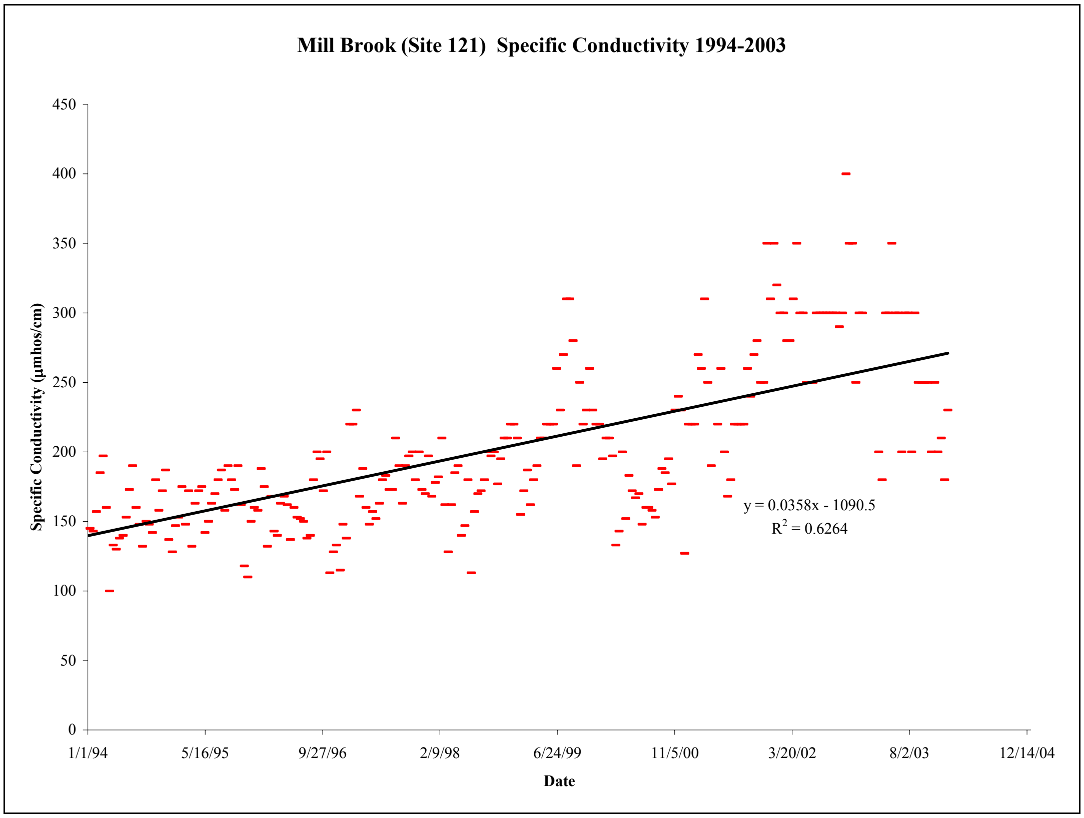


Figure 11

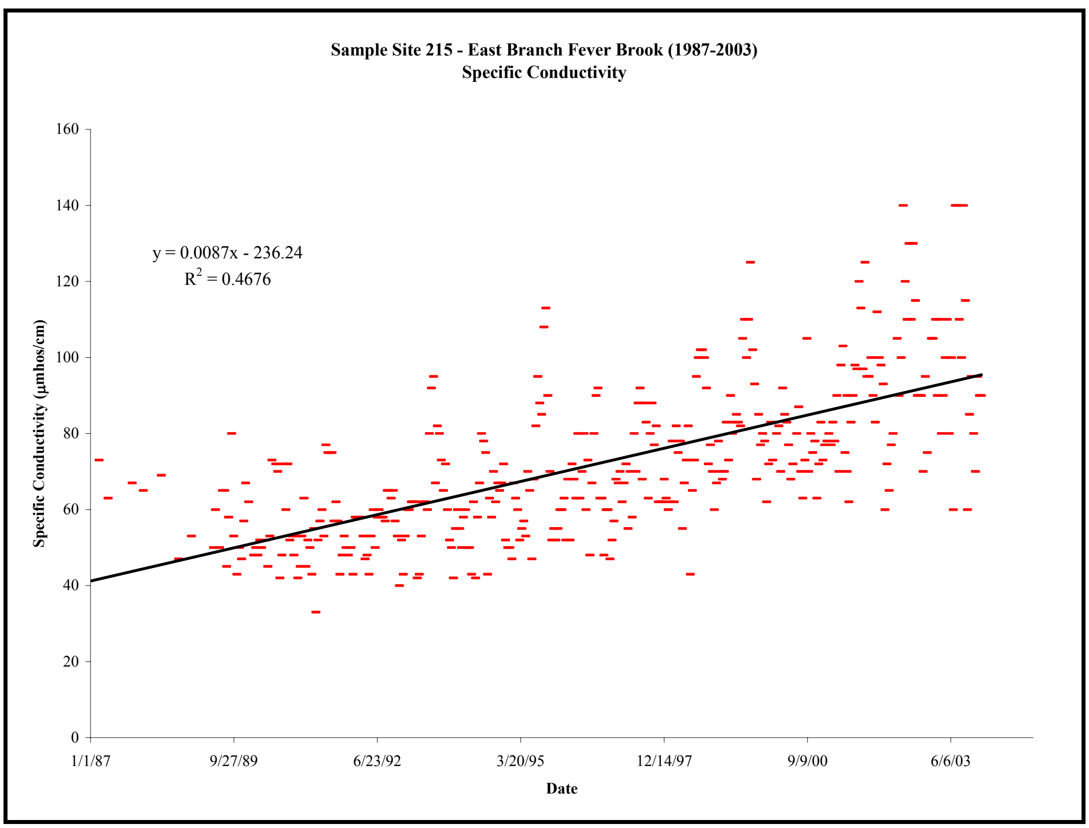


Figure 12

2.5 Reservoir Monitoring

The reservoir monitoring program builds on a historic data set that is used to track the ecological health of the reservoir and to detect trends that may signal changes to the trophic status of the reservoir. Water quality data is collected monthly except during periods of adverse weather and ice conditions in the winter. Three sampling stations that were routinely sampled in 2003 are profiled in **Table 11**. **Figure 8** may be referenced for the specific locations of each sample site.

Table 11 – 2002 Quabbin Reservoir Water Quality Monitoring Sites

Site	*Location*	*Latitude Longitude*	*Approximate Bottom Depth*
Winsor Dam (QR202)	Quabbin Reservoir west arm, off shore of Winsor Dam along former Swift River riverbed.	N 42°17’15” W 72°20’59”	44 meters
Shaft 12 (QR06)	Quabbin Reservoir at site of former Quabbin Lake, off shore of Shaft 12.	N 42°22’11” W 72°16’53”	28 meters
Den Hill (QR10)	Quabbin Reservoir eastern basin, north of Den Hill	N 42°23’23” W 72°15’57”	20 meters

Water samples were collected at depth with a kemmerer bottle and analyzed at Quabbin laboratory for turbidity, pH, alkalinity and color. Samples for total and fecal coliform bacteria are taken at the surface, 5 meter depth and at the respective water supply intake depth. Physiochemical samples are taken from mid-epilimnion and mid-hypolimnion during times of thermal stratification, and near the top and bottom during periods of isothermy and mixing. Wind, weather, reservoir conditions and air temperature are recorded on each survey. A standard 20 cm diameter black and white secchi disk is used to measure transparency.

Water column profiles of temperature, pH, dissolved oxygen, and specific conductance are measured “in-situ” using a Hydrolab Data Sonde 4a multiprobe. Readings are taken every meter during times of thermal stratification and mixing, and every three meters during periods of isothermy. Field data is stored digitally in a hand-held Hydrolab Surveyor 4A and transferred to a computer database maintained at Quabbin laboratory.

This report is supplemented by reservoir nutrient and phytoplankton results from quarterly sampling performed by DCR limnologist, Dave Worden. Quarterly sampling was conducted at the onset of thermal stratification (May), in the middle of the stratification period (late July), near the end of the stratification period (October), and during a winter period of isothermy (December). The MWRA Central Laboratory provided analytical support for the measurement of total phosphorous, total kjeldahl nitrogen, nitrate, ammonia, UV_{254} absorbance and silica.

Table 12 presents an overview of reservoir water quality conditions at three stations routinely monitored in 2003. The complete data for individual stations is included in the Appendix. Provided below is a brief discussion of selected monitoring parameters and their significance to reservoir water quality conditions. In general, water quality results fell within historic ranges, however, dynamic fluctuations were observed in reservoir total coliform bacteria levels.

Table 12. General Water Chemistry. 2003 Quabbin Reservoir Monitoring Stations.

	pH	**Turbidity**	**Color**	**Dissolved Oxygen**	**Secchi Disk Transparency**	**Specific Conductance**
Reservoir Station	Range (units)	Range NTU	Range CU	Range % Saturation	Range (meters)	Range (µmhos/cm)
Winsor Dam (QR202)	5.6-7.2	0.1-0.3	0-15	75.9-129.8	8.0-13.0	41.6-47.0
Shaft 12 (QR206)	6.2-7.0	0.1-0.4	0-15	49.2-130.1	7.7-11.5	41.7-47.5
Den Hill	6.0-6.9	0.3-0.6	10-25	52.2-116.2	3.8-6.9	51.1-68.2

Total Coliform Bacteria

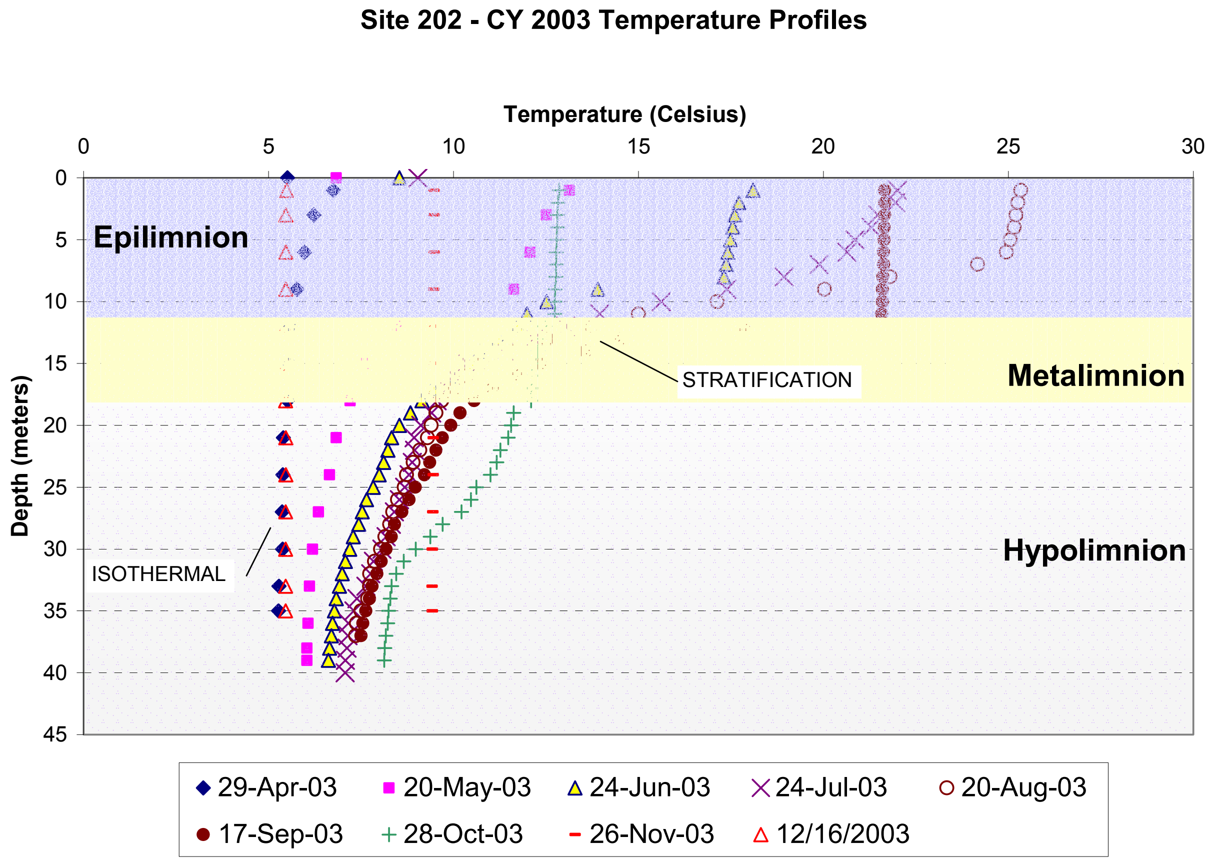
In-reservoir total coliform bacteria levels were monitored at the routine reservoir stations monthly beginning on April 29 and ended on December 16. Grab samples were collected from the surface, at the five meter depth, and from the respective water supply intake depth at the two deep basin sites (Shaft 12 and Winsor Dam). Peak densities were measured at 400 colonies per 100 mL in samples collected at site 202 (20 August) and Site 206 (28 October), at depths of 18 meters and 29 meters respectively. Insufficient data was collected to accurately characterize in-reservoir total coliform dynamics observed during the mid-summer to mid-fall months.

Fecal Coliform Bacteria

In-reservoir concentrations of fecal coliform bacteria, monitored monthly, remained very low. Of the 60 samples collected, only 14 (23%) tested positive for fecal coliform bacteria. The maximum concentration was measured at 3 CFU per 100 mL. Seasonal gull populations that roost on the reservoir overnight have been identified as the primary contributor of fecal coliform bacteria contamination to the reservoir. Other sources may include other waterfowl, semi-aquatic wildlife and tributary inputs.

Temperature

The thermal stratification that occurs in the reservoir has a profound impact on many of the parameters monitored across the reservoir profile. The temporal zones that develop within the reservoir during the warmer months of spring and summer, known as the epilimnion, metalimnion and hypolimnion (listed in order from top to bottom), have distinct thermal, water flow and water quality characteristics. Waters of the epilimnion are warm and well mixed by wind driven currents, and, may become susceptible to algal growth due to the availability of sunlight and entrapped nutrients introduced to the partitioned layer of surface water. Within the metalimnion the thermal and water quality transition occurs between the warmer surface waters and colder, deep waters. The



Source: 2003 DCR Quabbin Laboratory

Figure 13

much deeper hypolimnic waters remain stagnant, have no circulation, and are susceptible to decaying matter and sediments that settle out from the upper layers of warmer water. Each year the reservoir is completely mixed due the settling of cooler surface waters in the fall and following springtime ice-out when an isothermal water column is easily mixed by winds. Profile data collected a Station 202 has been selected to graphically portray the thermal mixing and transition that occurs between fully mixed, isothermal to fully stratified conditions.

Dissolved Oxygen

Dissolved oxygen profile measurements at Station 202 are displayed graphically below in Figure 9. Oxygen is essential to the survival of aquatic life (trout need a minimum of 5.0 mg/L or 44% saturation at 10°C) and available oxygen also plays an important role in preventing the leaching of potentially harmful toxins trapped among the bottom sediments. Dissolved oxygen, or more specifically the loss of oxygen from the hypolimnion, is used is as one index to characterize the trophic state of a lake. Because re-aeration factors such as wind driven turbulence, reservoir currents, and atmospheric diffusion diminish with depth dissolved oxygen concentrations typically decrease with depth. Dissolved oxygen reductions are most pronounced inside the hypolimnic layer of the reservoir where the water remains stagnant and microbial decomposition activity is a large consumer of the available oxygen. Hypolimnic oxygen reserves established in the spring are not replenished until the late fall when cooling surface waters ultimately settle and re-mix the reservoir. In 2003, minimum levels of oxygen reached in the hypolimnion ranged from a low of 49.2% saturation at the Shaft 12 station to 75.9% saturation at the bottom depths at Site 202. Depletion levels were most pronounced in the latter stages of stratification (September and October) and at no time were anaerobic conditions measured.

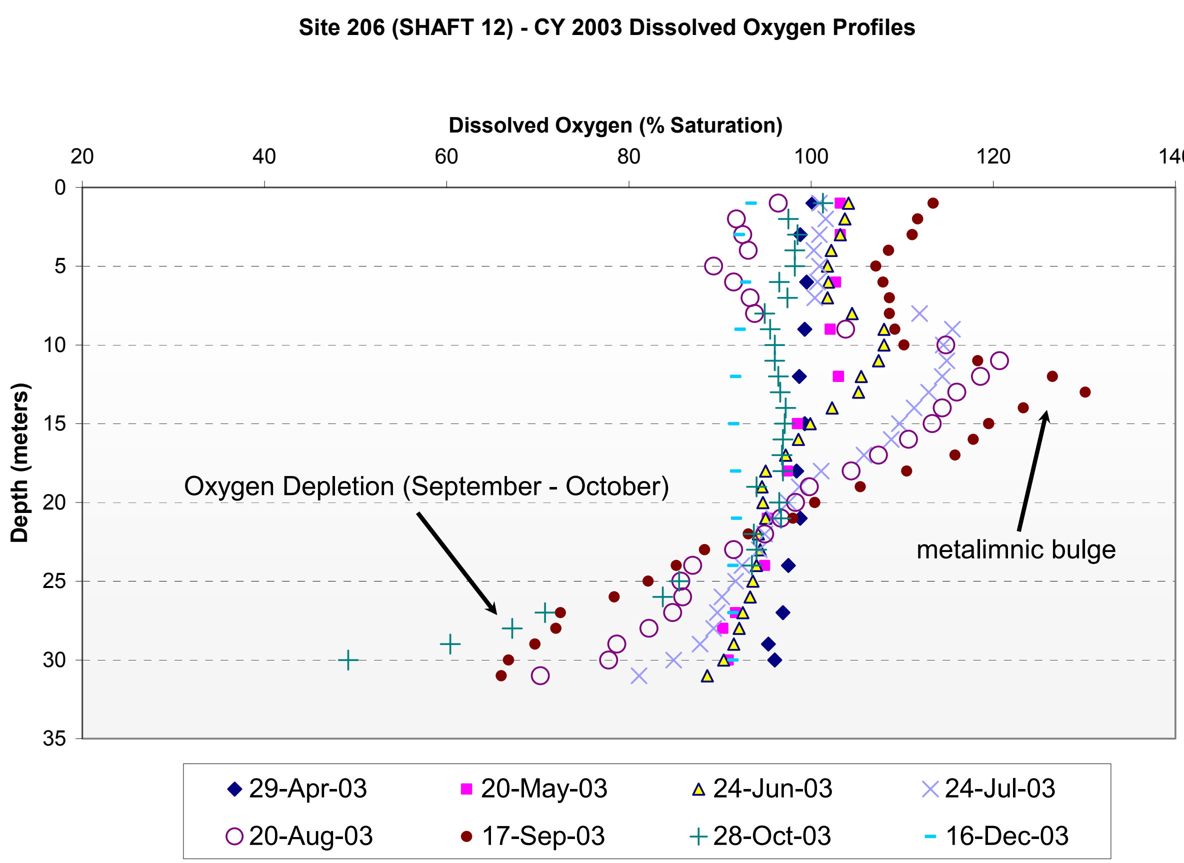
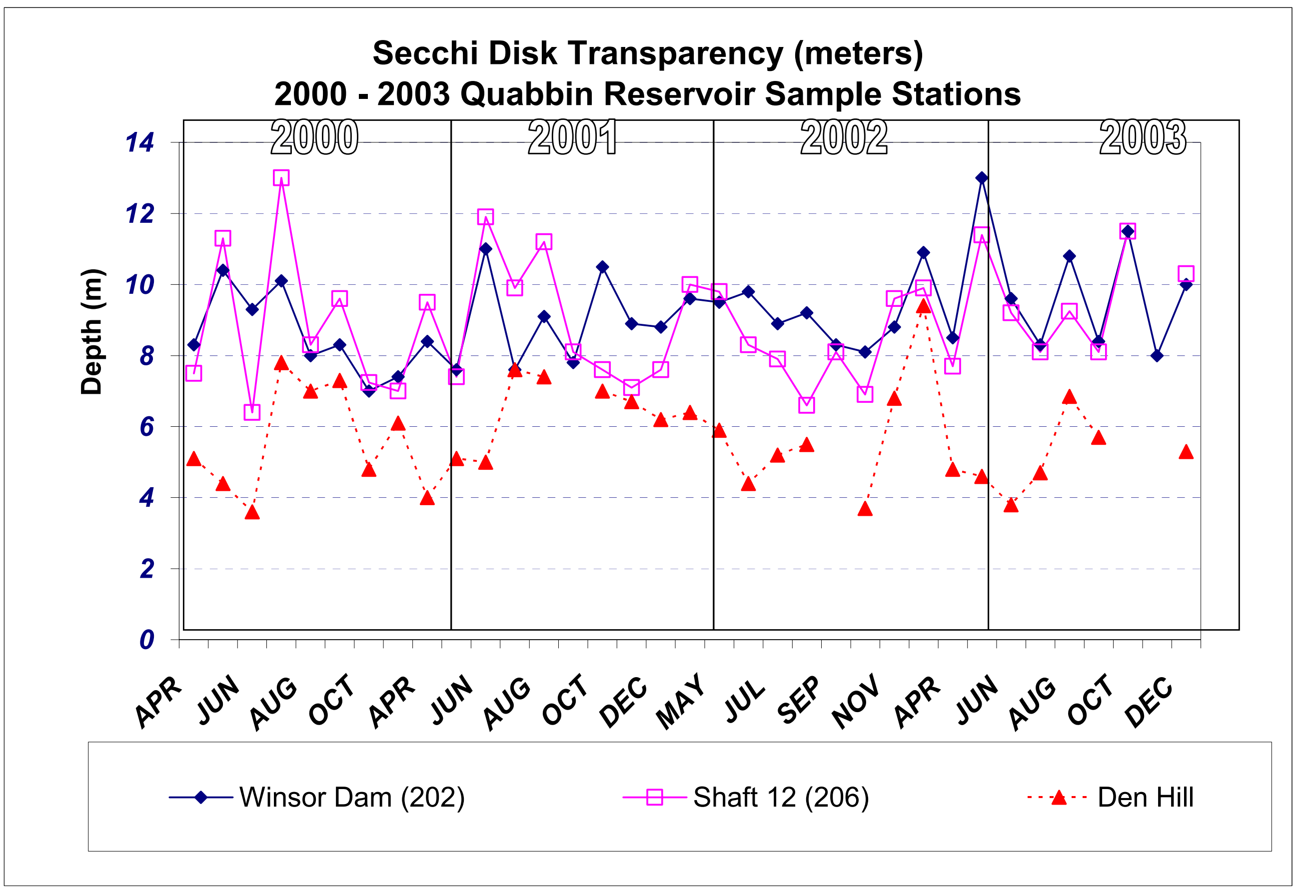


Figure 14

In the metalimnion and epilimnion, oxygen is typically abundant and often super-saturated. In this region the photosynthesis of phytoplankton becomes a factor as it serves as a significant source of oxygen. Another phenomenon that occurs in this region is called the "metalimnic bulge" and is characterized by increasing concentrations of oxygen with depth. The bulge is created when photosynthetically generated oxygen inside the metalimnion becomes entrapped and accumulates inside of the density-restricted zone (depicted in **Figure 14**).

Secchi Disk Transparency

Transparency is a measure of the water's clarity. It is determined as the depth below the surface at which a 20 centimeter black and white disk becomes indistinguishable to the naked eye. Transparency can be greatly influenced by the level of phytoplankton activity but is also sensitive to weather and reservoir conditions at the time of sampling. Quabbin Reservoir's exceptional clarity is evident in the fact that transparency measurements will extend into the metalimnion. In 2003, transparency was measured at a maximum of 13.0 meters at Site 202 on May 20. The Den Hill station is characteristically much lower and reflects the contribution of large, nearby river inputs of the East Branch Swift and Ware River (when diverting). The East Branch Swift River has been estimated to contribute as much as 9% of the annual flow to the reservoir. In 2003, Ware River diversions accounted for as much as 19.5% of the storage gain to the reservoir. In 2003, transparency was measured at a minimum of 3.8 meters at Den Hill on June 24. Monthly transparency measurements dating back to 2000 are displayed in **Figure 15**.



Turbidity and Color

Reservoir turbidity and color levels are very low, reflective of the low productivity of the reservoir. In-reservoir turbidity levels monitored in 2003 ranged from 0.1 to 0.6 NTU. From time to time, algae blooms may impart color and suspended organic particulates will elevate levels of turbidity and color. Color values ranged from 0 to 25 color units and were highest at Den Hill where the influence of tributary inputs, higher in organic content, are evident. Color levels did not go above 15 CU at either of the two, deep reservoir stations located at Shaft 12 and Winsor Dam.

pH and Alkalinity

Three processes principally reflected in reservoir pH and alkalinity dynamics are 1) direct acidic inputs (i.e., rainfall, dry deposition), 2) biological respiration and 3) algal photosynthesis. The input of acid in the form of direct precipitation will consume alkalinity available in the water and reduce pH levels. Reservoir pH is a water quality issue of concern because levels below 6 increase the solubility of persistent heavy metals such as mercury, allowing the metal to be incorporated into the water system and thus more likely to accumulate in the tissue of living organisms such as fish. Quabbin Reservoir and many other northeastern lakes have posted fish consumption advisories that suggest limiting the quantity of fish consumed because of the presence of higher levels of mercury in the fish.

Alkalinity serves as a water body's principal defense by neutralizing the effects of pH. Both pH and alkalinity have a long-term record of stability in the Quabbin Reservoir but levels will fluctuate due to reservoir dynamics. Fluctuations may be caused through respiration by organisms as oxygen is consumed and carbon dioxide is released. The result will be an increase in alkalinity due to the input of carbon to the water. Photosynthetic activity in the epilimnion and metalimnion can decrease alkalinity and increase pH due to the consumption of free carbon dioxide and bicarbonate.

Reservoir water is slightly acidic with pH in the epilimnion slightly higher than the bottom waters. In 54 grab samples collected from the reservoir stations the average pH level was 6.64. Reservoir alkalinity is low and averaged 4.0 mg/L as $Ca\ CO_3$ across the three reservoir stations with very little variation observed at depth. In-lab reservoir pH was consistently higher than field measurements taken with the Hydrolab Datasonde 4a multiprobe. The difference is being attributed to the low ionic strength of Quabbin Reservoir water. In 2004, a new low ionic strength pH probe will be installed on the Datasonde 4a in hopes of achieving better consistency between field and in-lab pH measurements.

Reservoir Phytoplankton and Nutrient Dynamics

The 2003 results from quarterly sampling build on a dataset begun by the DCR in 1998. The MWRA Central laboratory measures for total phosphorus, UV_{254}, silica, total Kjeldahl-nitrogen, nitrate, and ammonia-nitrogen. Phytoplankton analysis has been performed by Dave Worden, DCR Limnologist who contributed the synopsis of 2003 results presented below.

Results of quarterly nutrient sampling in 2003 document concentrations and intensities that register almost entirely within historical ranges. The exceptions are minor increases in the ranges of ammonia (epilimnetic values at Station 202 and Den Hill measured in December) and UV_{254} absorbance (values measured in May and July; see **Table 13** and quarterly database). However, these range increases are small increments and appear to have no significant water quality implications.

The patterns of nutrient distribution in 2003 quarterly samples were comparable to those documented previously in the 2000 report on Quabbin nutrient and plankton dynamics. These patterns consist of the following: (1) prominent seasonal and vertical variations due to demand by phytoplankton in the trophogenic zone (low concentrations in the epilimnion and metalimnion) and decomposition of sedimenting organic matter in the tropholytic zone (higher concentrations accumulating in the hypolimnion), (2) a lateral gradient in silica concentrations correlated to hydraulic residence time and mediated by diatom population dynamics, (3) and slightly higher concentrations and intensities at the Den Hill monitoring station due to the loading effects of the Ware River diversions and contributions from the East Branch Swift River. Future nutrient sampling at Quabbin Reservoir is planned to continue on the established quarterly schedule.

Table 13 - Quabbin Reservoir Nutrient Concentrations:

Comparison of Ranges from 1998-02 Database[(1)] to Results from 2003 Quarterly Sampling [(2)]

Sampling Station [(3)]	Ammonia (NH3; ug/L)		Nitrate (NO3; ug/L)		Silica (SIO2; mg/L)		Total Phosphorus (ug/L)		UV254 (Absorbance/cm)	
	1998-02	Quarterly'03	1998-02	Quarterly'03	1998-02	Quarterly'03	1998-02	Quarterly'03	2000-02	Quarterly'03
WD/202 (E)	<5 - 11	<5 - 16	<5 - 23	<5 - 18	0.84 - 1.73	1.24 - 1.55	<5 - 12	<5 - 10	0.017 - 0.022	0.021 - 0.025
WD/202 (M)	<5 - 29	<5 - 13	<5 - 27	<5 - 19	0.83 - 1.79	1.32 - 1.44	<5 - 13	<5 - 7	0.017 - 0.025	0.019 - 0.027
WD/202 (H)	<5 - 53	9 - 36	<5 - 54	18 - 46	1.08 - 2.58	1.36 - 1.76	<5 - 44	<5 - 7	0.017 - 0.024	0.018 - 0.023
MP/206 (E)	<5 - 8	<5 - 7	<5 - 20	<5 - 17	0.84 - 1.52	1.15 - 1.39	<5 - 12	<5 - 6	0.017 - 0.024	0.022 - 0.025
MP/206 (M)	<5 - 34	<5 - 6	<5 - 44	<5 - 17	0.84 - 1.56	1.10 - 1.36	<5 - 9	<5 - 7	0.017 - 0.027	0.021 - 0.029
MP/206 (H)	<5 - 105	6 - 27	<5 - 29	17 - 24	1.02 - 1.92	1.18 - 1.44	<5 - 12	<5 - 8	0.018 - 0.026	0.020 - 0.023
Den Hill (E)	<5 - 16	<5 - 19	<5 - 45	<5 - 32	0.74 - 4.64	1.27 - 3.30	<5 - 15	<5 - 12	0.025 - 0.112	0.054 - 0.085
Den Hill (M)	<5 - 25	<5 - 20	<5 - 58	<5 - 37	0.84 - 4.37	1.12 - 3.12	<5 - 15	5 - 9	0.027 - 0.090	0.055 - 0.087
Den Hill (H)	<5 - 84	21 - 41	<5 - 74	32 - 72	0.83 - 4.25	2.33 - 4.22	<5 - 15	6 - 11	0.028 - 0.085	0.080 - 0.103

Notes: (1) 1998-02 database composed of 1998-99 year of monthly sampling and subsequent quarterly sampling conducted through December 2002, except for measurement of UV254 initiated in 2000 quarterly sampling

(2) 2003 quarterly sampling conducted May, July, October, and December

(3) Water column locations are as follow: E = epilimnion/surface, M = metalimnion/middle, H = hypolimnion/bottom

3.0 SPECIAL INVESTIGATIONS

Provided below is a brief overview of specialized studies and investigations that involved Quabbin Reservoir and its contributing tributaries.

Event Based Pathogen Monitoring Research Project – University of Massachusetts

In 2003, the DCR continued a collaborative effort with the University of Massachusetts, Environmental Engineering Program on an AWAARF study to quantify storm water generated, microbiological loadings from various land uses. Water quality monitoring is being conducted at two wildlife study sites located on Prescott Peninsula and at an upstream and downstream station bordering a farm site in the Ware River watershed. In 2003 the Quabbin laboratory processed and analyzed 131 samples for total and fecal coliform bacteria. Samples were collected on a monthly basis to quantify baseline conditions and on five occasions during storm events. Data analysis is pending as researchers continue to gather more data.

Tributary Mixing Studies

A study was initiated at the mouth of Hop Brook to use conductivity differences to track the inflow into Quabbin Reservoir. Hop Brook was chosen because of the conspicuous differences between tributary and reservoir conductance levels. DCR staff collected measurements of temperature and specific conductance at depth and along a horizontal transect that extended approximately 400 meters beyond the mouth of the tributary. A previous attempt at evaluating tributary mixing lengths was performed by a summer NSF/REU (National Science Foundation/Research for Undergraduate Experience) student between June and July 1998. At that time differences in tributary TOC and UV absorbance levels were utilized as a tracer and mixing lengths were estimated to range between 50 to 1000 meters. Differences in mixing lengths were attributed to a number of conditions such as stream flow, wind speed and direction, and temperature gradients.

In 2003, DCR staff conducted monitoring events at the mouth of Hop Brook on March 19 and March 21. The sampling event was unique because at the time twenty inches of ice covered the surface of the reservoir. This meant that wind driven currents would be non-existent. Satff utilized an ice auger and a Hydrolab DataSonde 4a multiprobe to gather temperature and specific conductance profiles.

The monitoring event on March 19 was considered a dry weather, good flow event. Brook discharge was estimated at 38.1 cfs based on a USGS staff gage established at the tributary mouth. Division staff profiled temperature and conductivity at three locations for this event, and conditions can generally be described as static. The monitoring event on March 21 was considered a wet weather, high flow event. Brook discharge was estimated at 100 cfs. For this event, staff profiled temperature and conductivity at seven locations along a horizontal transect between the tributary entry point and the main inlet area. Conductivity profiles on this date are plotted as isohalines in **Figure 16** and can be described as dynamic.

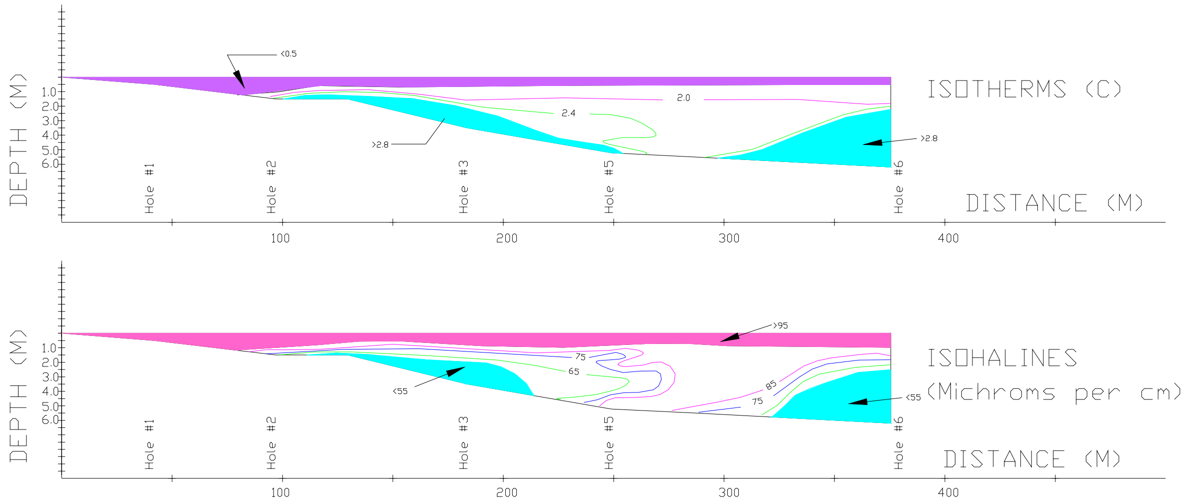


Figure 16 – Hop Brook Isotherms and Isohalines (March 21, 2003).

On March 21, conductivity results indicated that tributary levels entering the inlet were at 102.6 µs/cm. The brook temperature was about 0.4˚ C. Conductivity levels profiled in the reservoir inlet ranged from 48.4 to 114.9 µs/cm. The highest conductivity levels were confined to the first 0.5 meter depth and it is suspected that levels were being inflated because of the effects of melting ice. Temperatures profiled in the inlet ranged from 0.32 to 3.13˚ C. The lowest temperatures (<0.5˚ C) corresponded to the upper surface waters where influence from melting ice, and, for those sites closest to the tributary mouth, the influence from pure brook water was apparent. Higher temperatures (>2.8˚ C) were indicative of heavier (i.e. more dense), bulk reservoir water located on the bottom depths. Figure 16 gives some indication that for the first 200 meters away from the mouth, cold brook water traveled along a horizontal pathway as plug flow close to the surface of the water. The first indication of vertical mixing could be seen in profile measurements at Hole #5. At this location conductivity ranged between 64.1 and 144.9 µs/cm and levels varied inconsistently with depth. At Hole #5 bulk reservoir water (i.e. < 55 µs/cm) was not detectable and there were clear horizontal gradients indicative of mixing. Temperature across this profile also moderated from top to bottom with a notable absence of bulk reservoir water (>2.8 ˚C). This "moderation" of temperatures with depth also serves to breakdown density gradients further enabling plunging and mixing actions to occur. Tributary mixing length for Hop Brook was estimated to range between 225 to 400 meters. At the upper limit of 400 meters (holes #4 , #6 & #7), higher conductivity levels at the surface were not entirely attributed to the effects of melting ice. It is believed that the lighter, less dense brook water floated along a horizontal pathway close to the ice/water interface, thereby extending the mixing zone to these outer fringes. No measurements were made beyond 400 meters.

2003 Beach Monitoring Program

The public bathing beach at Asnacomet Pond was opened on July 1 and closed after September 1. During this time period the beach was officially open for 36 days. DCR staff collected weekly water samples from the beach area and tested them for fecal coliform bacteria and *E. Coli* bacteria levels.

Samples were collected at three locations and water temperature was measured. A running geometric mean of the previous five *E. Coli* measurements never exceeded 6 CFU per 100 mL. Beach monitoring results are summarized in **Table 14**.

Table 14. Select Water Quality Parameters

Comet Pond Beach, Hubbardston, MA

June – August 2003

MDC/DWM Sample Date	Sample Location off Comet Pond Beach	Water Temperature (°C)	Fecal Coliform Bacteria (# colonies/100 mL)	*E. Coli* (#colonies/100 mL)	Geometric Mean of last five samples *E. Coli* (samples with at least 1 colony)
6/25/03	Left	21°	1	2	NA
	Middle	21°	1	4	NA
	Right	21°	0	1	NA
7/2/03	Left	22°	1	1	NA
	Middle	22°	1	2	NA
	Right	22°	4	0	NA
7/9/03	Left	24°	11	15	2
	Middle	24°	6	15	3
	Right	24°	15	11	3
7/16/03	Left	24°	0	1	6
	Middle	24°	1	1	6
	Right	24°	0	4	5
7/23/03	Left	24°	1	1	2
	Middle	24°	2	1	2
	Right	24°	1	3	1
7/30/03	Left	25°	0	0	2
	Middle	25°	1	0	2
	Right	25°	0	0	2
8/6/03	Left	29°	7	5	2
	Middle	29°	4	2	2
	Right	29°	6	5	2
8/13/03	Left	25°	5	5	3
	Middle	25°	5	3	4
	Right	25°	1	3	4
8/20/03	Left	24°	0	1	3
	Middle	24°	0	0	3
	Right	24°	0	0	3
8/27/03	Left	24°	1	0	3
	Middle	24°	0	2	3
	Right	24°	1	1	3

Source: (DCR Quabbin Lab Records, 2003)

References:

American Public Health Association, 1998. Standard Methods for the Examination of Water and Wastewater - 20th Edition. Washington D.C..

Byappanahalli, M., M. Fowler, D. Shevely and R. Whitman. 2003. Ubiquity and Persistence of *Escherichia coli* in a Midwestern Coastal Stream. Applied and Environmental Microbiology. 69 (8):4549-4555.

Crabill, C., Donald, R., Snelling, J., Foust, R. and Southam, G.. 1999. The Impact of Sediment Fecal Coliform Reservoirs on Seasonal Water Quality in Oak Creek, Arizona. Water Research. 33(9):2163-2171.

Garvey, E.A., Tobiason, J.E., Reckhow, D.A. and Edzwald, J.K.. October 2000. Natural Organic Matter Fate and Transport in Quabbin Reservoir. Dept. of Civil and Environmental Engineering, University of Massachusetts, Amherst.

Geldreich, E.E., 1968. "Fecal Coliform Concepts in Stream Pollution." Proceedings Symposium on Fecal Coliform Bacteria in Water and Wastewater, Bureau of Sanitary Engineering, State Dept. of Public Health, Berkeley, California.

Hanes, N.B., G. A. Delaney and C. J. O'Leary. 1965. Relationship between Escherichia coli, Type I, coliform and enterococci in water. **J**. *Boston Soc. of Civil Engineers 52:129-140.*

Jakubowski, J. et al, September 1996. "Environmental Methods for Cryptosporidium". Journal American Water Works Association.

Lee, Yuehlin, February 2004. Total Coliform Trends in Quabbin Reservoir, 1995-2002. Dept. of Civil and Environmental Engineering, University of Massachusetts, Amherst.

Lent, R.M., Waldron, M.C and Rader, J.C.. April 1998. "Multivariate Classification of Small Order Watersheds in the Quabbin Reservoir Basin, Massachusetts." Journal of the American Water Resources Association, Vol. 34, No. 2.

Long, S.C., May 1997. Development of Methods to Differentiate Microorganisms in MDC Reservoir Watersheds. Dept. of Civil and Environmental Engineering, University of Massachusetts, Amherst.

MA Executive Office of Environmental Affairs, 1999. MA Geographical Information System.

Metropolitan District Commission, 2003. Meteorological and Yield Data Records. MDC unpublished reports.

Overacre, R.C.. November 2003. Effects of Road Salt on Sedimentary Phosphorous Remobilization in an Urban Pond. Environmental Engineering, Tufts University.

Shanley, J.B.. 1994. "Effects of Ion Exchange on Stream Solute Fluxes in a Basin Receiving Highway Deicing Salts." Journal of Environmental Quality, 23:977-986.

Streeter, H.W., 1934. "Formulation of Bacterial Changes Occurring in Polluted Water." *Sewage Works Journal*, Vol. 6, No. 2.

Tobiason J.E., Male J.W., Reckhow D.A., September 1996. Contaminant Transport Modeling and the Impact of Watershed Management Activities on Water Quality in Quabbin Reservoir. Environmental Engineering Program, University of Massachusetts at Amherst.

Ulrich, B.. 1980. Production and Consumption of Hydrogen Ions in the Ecosphere. In T.C. Hutchinson and M. Haves (eds), *Effects of acid precipitation on terrestrial ecosystems*, 255-82. New York. Plenum Press.

U.S. EPA, 1986. <u>Water Quality Criteria for Water</u>

Waite, T.D. 1984. <u>Principles of Water Quality</u>. Academic Press, Florida.

Wolfram, Evelyn. May 1996. Determination of the Decay Rate For Indicator Bacteria Introduced by Sea Gulls to an Oligotrophic Drinking Water Reservoir. M.S. Thesis, Department of Civil and Environmental Engineering, University of Massachusetts at Amherst.

Worden, David. 2000. Nutrient and Plankton Dynamics in Quabbin Reservoir: Results of the MDC/DWM's 1998-99 Sampling Program. Metropolitan District Commission, Division of Watershed Management.

APPENDIX A
WATER QUALITY DATA TABLES

APPENDIX B
WATER QUALITY DATA PLOTS

APPENDIX C
USGS STREAM DISCHARGE DATA